# Modern Marine Electricity

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# PREFACE

A few years ago, shipbuilding in the United States took a new lease on life. Under the guidance of the United States Maritime Commission new cargo vessels were designed, and an era of intensive shipbuilding got underway.

The design of these ships reflects the very best practice known, and is being consistently modified and improved. Today almost all engine room auxiliaries and deck machinery are electrically driven. Twenty years ago most of these were steam driven, and the only electrical equipment on the ship was the "lighting dynamo."

As a result, the ship's electrician now finds himself in one of the most difficult and responsible jobs aboard ship. Little information is available on his work that is not outmoded. There was need for a modern marine electricity handbook, and this book has been written in an attempt to fill the need.

It is designed principally for the operating marine electrician, and is not a text on electrical theory. There are already many such works. It embraces that part of the ship's electrical design which he should know to better understand his job, with information on maintenance which will prove helpful. Generating equipment, auxiliary machinery drives, electric couplings, electric propulsion equipment, deck machinery and interior communication are discussed in detail.

It is further felt that this book will prove useful to the marine engineer, and also the shore electrician who wishes to go into the marine field.

Electrical installation on American ships is designed in accordance with the Marine Standards of the American Institute of Electrical Engineers. Part of these standards have been included by permission, for which the author wishes to express special appreciation, as well as for permission to use the paper on electric couplings by M. R. Lory, L. A. Kilgore and R. A. Baudry.

Acknowledgment is made for material furnished by the Westinghouse Electric & Manufacturing Company, which also supplied valuable notes on maintenance; by the Electro-Dynamic Works of the Electric Boat Company; and by the General Electric Company.

The author also takes this opportunity to thank the many friends who have made helpful suggestions.

*Beaumont, Texas* P. DE W. SMITH
*June 25, 1941*

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# Modern Marine
# Electricity

# I

# INTRODUCTION

All marine engineers and many electricians have, at one time or another been confronted with electrical problems of a practical nature, which with a little special knowledge could have been solved satisfactorily.

Today the engine room auxiliaries—pumps, compressors, blowers, centrifuges, etc.—are electrically driven. This is true also of the deck machinery, steering gear and navigating equipment. The quartermaster steers by an electrically-driven gyro-compass, and the course he sets is continued automatically by a gyro-pilot, by merely moving a lever. The angle of the ship's rudder is indicated in the wheelhouse electrically; so also is the engine speed, direction of rotation and total number of revolutions.

Continuous soundings are made by an electric fathometer. Even the whistle is electrically controlled. An alarm sounds in the wheelhouse if one of the ship's running lights goes out, and the watch officer can turn on a spare filament at a moment's notice; while some equipment does the job automatically.

Telephones connect as many deck and engine room stations as required. Radio keeps in touch with other ships and shore, receiving time signals and weather reports as well as bearings.

An alarm warns the watch engineer of a temperature rise in the cooling water system or a pressure drop in the lubricating oil system. Another warns him when the tanks are full, when loading fuel oil.

All electric galleys are supplied with electric powered mixers, proofing boxes, coffee makers, toasters and even egg timers.

Radio broadcast antennas with multiple outlets provide for the crew's comfort, not to mention electric fans.

Electric propulsion also is used in vessels from small Diesel tugs with electric towing engines, fire boats and electric ferries, up to the largest liners.

With this ever-increasing use of electricity for propulsion, auxiliaries and deck machinery, it becomes extremely important for the marine engineer and electrician to be familiar with modern equipment.

In the operation and maintenance of electrical machinery on shipboard, a broad general knowledge of AC and DC motors, generators, converters, switchboards, contactors, control panels, remote-control switches,

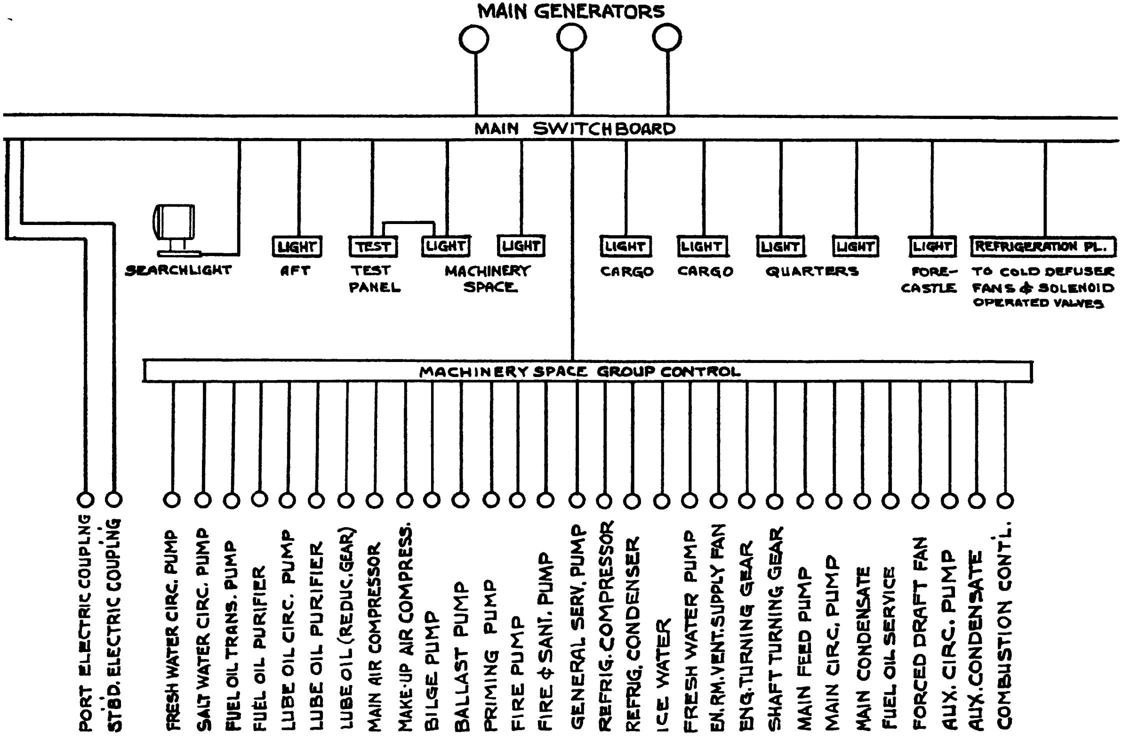

FIG. 1A. Section of distribution system for steam and Diesel driven ships. The main switchboard bus extends to Figs. 1B and 1C.

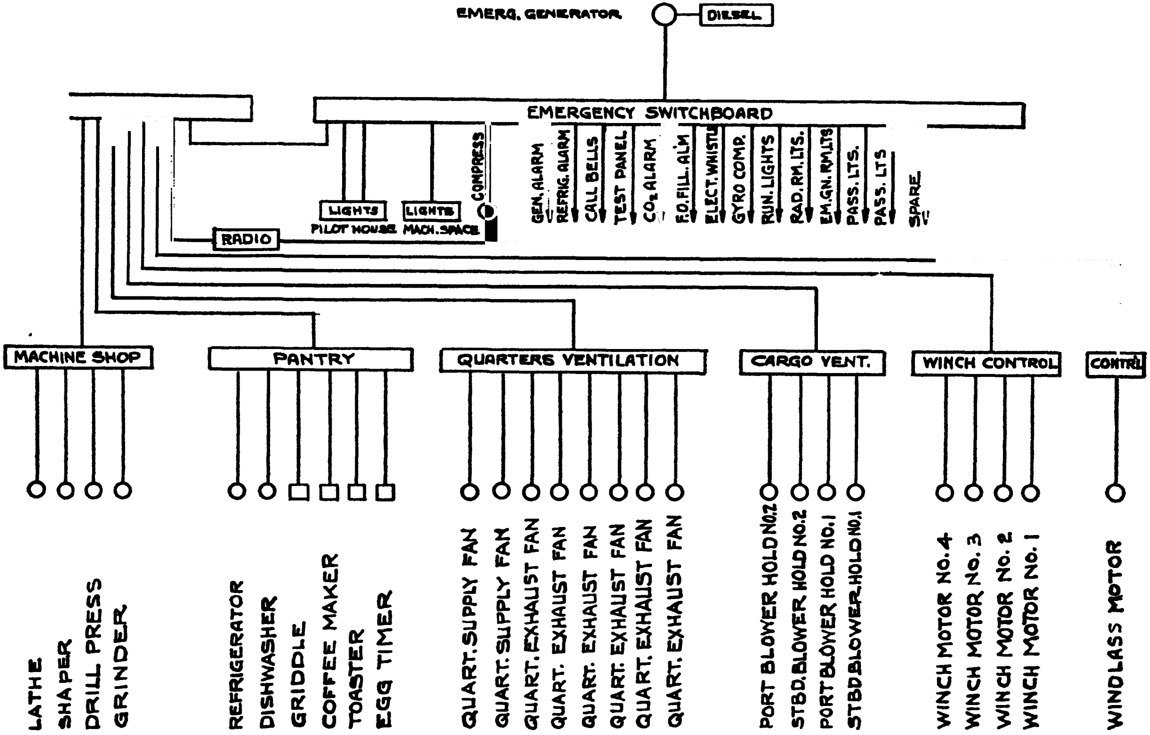

FIG. 1B. Extension of main switchboard bus (Fig. 1A) and emergency hookup.

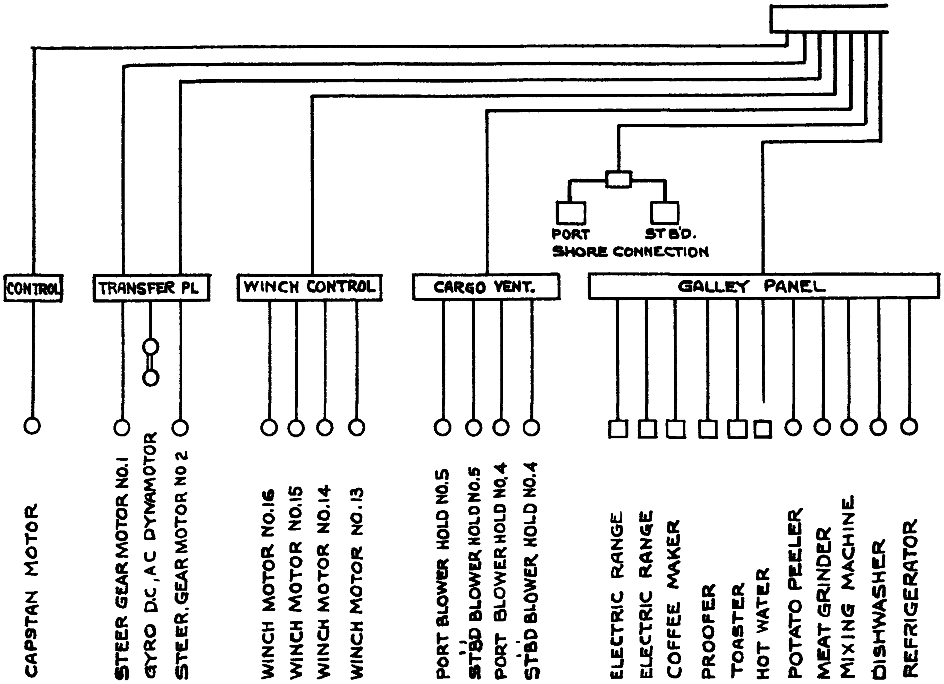

FIG. 1C. The other extension of main switchboard bus (FIG 1A) and emergency hookup.

circuit breakers, etc., is a necessary requirement. A knowledge of repairs that can be made aboard ship is also of utmost importance.

The source of electric power on merchant ships is usually comprised of two or more generators arranged for parallel operation. These feed into a main switchboard, and from this point the power is distributed to the secondary distribution points such as the group control, the winch control and resistor houses, the steering gear transfer panel, ventilation panels, emergency switchboards, galley, machine shop, radio power panel, windlass, capstan, electro-magnetic couplings (when used with Diesel engines). Also cargo hold ventilation and laundry, quarters lighting panels, cargo lighting panel, engine room, aft and forecastle lighting panels. There is also a separate feeder for the searchlight.

The diagram in Fig. 1, A, B & C shows the general arrangement of electric power distribution on board ship.

In the following general discussion of the various equipment met with on shipboard, Ohm's Law and simple calculations will be included. Operation, care and repair will follow these discussions. But before taking up these discussions it seems practical to become familiar with certain definitions and classifications from the Standards of the American Institute of Electrical Engineers (A.I.E.E.): Electrical Installations on Shipboard. Excerpts from the Standards follow:

# EXCERPTS FROM STANDARDS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

## RECOMMENDED PRACTISE FOR ELECTRICAL INSTALLATIONS ON SHIPBOARD *

### SECTION 1—GENERAL

**Scope.** These Marine Recommendations have been drawn up to serve as a guide for the equipment of merchant vessels with electric apparatus for lighting, signaling, communication, power and propulsion. They indicate what is considered good engineering practise with reference to safety of the personnel and of the ship itself as well as reliability and durability of the apparatus; it is not intended however, that improvements, which may be developed from time to time, should be excluded.

These recommendations are intended to supplement the other standards of the A.I.E.E., which should be followed wherever applicable.

* This Revision Adopted by Board of Directors, June 27, 1940.

Attention is directed to the fact that regulations for electrical installations on shipboard are promulgated by the Maritime Commission, Department of Commerce, Bureau of Marine Inspection and Navigation, Federal Communications Commission and the American Bureau of Shipping (these recommendations have given due consideration to all the regulations), but since the above referenced sponsoring bodies are frequently modifying the requirements to meet changing conditions, reference should always be made to the latest edition of their requirements.

Distribution of electric energy may be made either by direct current or alternating current, but in present practise for electric auxiliaries direct current is usually employed. On this account, the main body of these recommendations covering auxiliaries relates to direct-current installations, but information is also given concerning recommended practise for alternating-current installations.

**Vessel classification.** The Bureau of Marine Inspection and Navigation has divided vessels into the following groups:

Group No. 1. Ocean going vessels which navigate on any ocean or the Gulf of Mexico more than 20 miles off-shore.
Group No. 2. Ocean going vessels which navigate on any ocean or the Gulf of Mexico but less than 20 miles off-shore.
Group No. 3. Vessels navigating Great Lakes only.
Group No. 4. Vessels navigating bays, sounds and lakes other than the Great Lakes.
Group No. 5. Vessels navigating rivers only.

**Vessel classification groups covered herein.** Since these Rules are promulgated only as recommendations, the general thought in their preparation has been for their application to all passenger and cargo vessels of Groups No. 1, No. 2 and No. 3, but it is believed that many of the recommendations are applicable to all groups of vessels if a high standard electrical installation is desired.

**Plans.** Every vessel should be provided with plans giving complete and detailed information as to circuits, wire sizes, load, etc., for the light, power and interior communication systems. A symbol list giving the manufacturer's name, size, type, rating, catalog number or similar identification for all the equipment on the vessel should also be provided for the vessel's operating personnel.

## SECTION 2—GENERAL DEFINITIONS

**Direct current.** A direct current is a unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

**Alternating current.** An alternating current is a current, the direction of which reverses at regularly recurring intervals. Unless distinctly otherwise specified, the term "alternating current" refers to a periodic current which has alternately positive and negative values.

**Cycle.** A cycle is one complete set of positive and negative values of an alternating current.

**Frequency.** The frequency of an alternating current is the number of cycles per second.

**Single-phase.** Single-phase is a term characterizing a circuit energized by a single alternating electromotive force.

**Three-phase.** Three-phase is a term characterizing the combination of circuits energized by alternating electromotive forces which differ in phase by one third of a cycle, *i.e.*, 120 degrees.

**Slip.** The slip of an induction machine is the difference between its synchronous speed and its operating speed and may be expressed in the following ways:

*a*) As a percent of synchronous speed.
*b*) As a decimal fraction of synchronous speed.
*c*) Directly in revolutions per minute.

**Embedded temperature detector.** An embedded temperature detector is a resistance thermometer or thermo-couple built into a machine for the purpose of measuring the temperature.

## SECTION 3—GENERATOR CLASSIFICATION

**Generator.** An electric generator is a machine which transforms mechanical power into electrical power. A generator producing direct current is usually called a DC generator, and a generator producing alternating current is called an AC generator or an alternator.

**Shunt-wound generator.** A shunt-wound generator is a direct-current generator in which the entire field excitation is derived from one winding consisting of many turns with a relatively high resistance. This one winding is connected in parallel with the armature circuit for a self-excited generator, and to the load side of another generator for a separately excited generator. Practically all direct-current generators installed on vessels for supplying auxiliary power are of the self-excited type. Direct-current propulsion generators are usually of the separately excited type.

**Compound-wound generator—ordinary type.** An ordinary compound-wound generator is a direct-current generator which has two separate field windings—one, supplying the predominating excitation, is connected in parallel with the armature circuit and the other, supplying only partial excitation, is connected in series with the armature circuit and of such proportion as to require an equalizer connection for satisfactory parallel operation.

**Compound-wound generator—special type.** Same as ordinary type, except that the series field winding is of such proportion as not to require equalizers for satisfactory parallel operation. (The voltage regulation of this type generator is to comply with that given for shunt-wound generators.)

**Magneto-electric generator.** A magneto-electric generator is an electric generator, the field poles of which are permanent magnets.

**Exciter.** An exciter is an auxiliary generator which supplies power for the field excitation of another electrical machine.

**Pilot exciter.** A pilot exciter is an exciter which supplies power for the field excitation of another exciter.

**Synchronous generator.** A synchronous generator is a synchronous alternating-current machine which transforms mechanical power into electrical power.

A synchronous machine is one in which the average speed of normal operation is exactly proportional to the frequency of the system to which it is connected.

**Single-phase synchronous generator.** A single-phase synchronous generator is one which produces a single alternating electromotive force at its terminals. It delivers electric power which pulsates at double frequency.

**Polyphase synchronous generator.** A polyphase synchronous generator is one whose alternating-current circuits are so arranged that two or more symmetrical alternating electromotive forces with definite phase relationships are produced at its terminals. Polyphase generators as used for marine service are generally three phase. For special cases they may be two phase.

**Inductor-type synchronous generator.** An inductor type synchronous generator is one in which the field coils are fixed in magnetic position relative to the armature conductors, the electromotive forces being produced by the movement of masses of magnetic material.

**Induction generator.** An induction generator is an induction machine, driven above synchronous speed by an external source of mechanical power.

## SECTION 4—MOTOR CLASSIFICATION

**Motor.** An electric motor is a machine which transforms electrical power into mechanical power.

**Universal motor.** A universal motor is a series wound or a compensated series wound motor which may be operated either on direct current or single-phase alternating current at approximately the same speed and output.

**Shunt-wound motor.** A shunt-wound motor is a direct-current motor in which the field circuit and armature circuit are connected in parallel.

**Stabilized shunt-wound motor.** A stabilized shunt-wound motor is a shunt-wound motor having a light series winding added to prevent a rise in speed or to obtain a slight reduction in speed, with increase of load.

**Series-wound motor.** A series-wound motor is a commutator motor in which the field circuit and armature circuit are connected in series. (It operates at a much higher speed at light load than at full load.)

**Compound-wound motor.** A compound-wound motor is a direct-current motor which has two separate field windings,—one, usually the predominating field, connected in parallel with the armature circuit, and the other connected in series with the armature circuit. (The characteristics as regards speed and torque are intermediate between those of shunt and series motors.)

**Induction motor.** An induction motor is an induction machine which converts electrical power delivered to the primary circuit into mechanical power. The secondary circuit is short-circuited or closed through a suitable circuit.

**Squirrel cage induction motor.** A squirrel cage induction motor is an induction motor in which the secondary circuit consists of a squirrel-cage winding suitably disposed in slots in the secondary core.

**Wound rotor induction motor.** A wound rotor induction motor is an induction motor in which the secondary circuit consists of polyphase winding of coils whose terminals are either short-circuited or closed through suitable circuits. (When provided with collector or slip rings, it is also known as a slip-ring induction motor.)

**Synchronous motor.** A synchronous motor is a synchronous machine which transforms electrical power from an alternating-current system into mechanical power. Synchronous motors usually have direct-current field excitation. A synchronous motor operates at synchronous speed and therefore operates with zero slip. The synchronous speeds depend upon the frequency of the supply system and the number of poles.

**Motor reduction unit.** A motor-reduction unit is a motor with an integral mechanical means of obtaining a speed differing from the speed of the motor.

**Amortisseur winding.** An amortisseur winding is a permanently short-circuited winding, usually uninsulated, so arranged as to oppose rotation or pulsation of the magnet field with respect to the pole shoes.

**Squirrel-cage winding.** A squirrel-cage winding is a permanently short-circuited winding, usually uninsulated (chiefly used in induction machines) having its conductors uniformly distributed around the periphery of the machine and joined by continuous end rings.

## SECTION 5—CONVERTERS: ROTARY

**Dynamotor.** A dynamotor is a machine which combines both motor and generator action in one magnetic field, either with two armatures, or with one armature having two separate windings. (The two windings may be in the same slots.)

**Motor generator set.** A motor generator set is a machine which consists of one or more motors mechanically coupled to one or more generators.

**Synchronous converter** (Rotary Converter). A synchronous converter is a synchronous machine which converts alternating current to direct current or vice-versa. The armature winding is connected to the collector rings and commutator.

**Synchronous condenser.** A synchronous condenser is a synchronous phase modifier running without mechanical load, the field excitation of which may be varied so as to modify the power factor of the system; or through such modification, to influence the load voltage.

**Direct-current balancer.** A direct-current balancer set is a machine which comprises two or more similar direct-current machines (usually with shunt or compound excitation) directly coupled to each other and connected in series across the outer conductors of a multiple-wire system of distribution, for the purpose of maintaining the potentials of the intermediate conductors of the system, which are connected to the junction points between the machines.

## SECTION 6—MOTOR SPEED CLASSIFICATION

**Constant-speed motor.** A constant-speed motor is one the speed at normal operation of which is constant or practically constant. (Example: A synchronous motor, an induction motor with small slip, or an ordinary direct-current shunt-wound motor.)

**Multispeed motor.** A multispeed motor is one which can be operated at any one of two or more definite speeds, each being practically independent of the load. (These are generally induction motors with special stator windings by which the number of poles can be changed by suitable switching appliances, so as to operate at more than one speed.)

**Adjustable-speed motor.** An adjustable-speed motor is one the speed of which can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load, such as a shunt motor with field resistance control designed for a considerable range of speed adjustment.

**Base speed of an adjustable-speed motor.** The base speed of an adjustable-speed motor is the lowest speed obtained at rated load and rated voltage at the temperature rise specified in the rating.

**Varying-speed motor.** A varying-speed motor is one the speed of which varies with the load, ordinarily decreasing when the load increases; such as a series motor, or an induction motor with large slip.

**Adjustable varying-speed motor.** An adjustable varying-speed motor is one the speed of which can be adjusted gradually, but when once adjusted for a given load will vary in considerable degree with change in load. (Example: Compound-wound direct-current motor adjusted by field control or a slip-ring induction motor with rheostatic speed control.)

## SECTION 7—VENTILATION OF MACHINES

**Open machine.** An open machine is a self-ventilated machine having no restriction to ventilation other than that necessitated by mechanical construction.

**Self-ventilated machine.** A self-ventilated machine is a machine which has its ventilating air circulated by means integral with the machine.

**Separately ventilated machine.** A separately ventilated machine is a machine which has its ventilating air supplied by an independent fan or blower external to the machine.

**Enclosed self-ventilated machine.** An enclosed self-ventilated machine is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means integral with the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet ducts or pipes may be connected to them.

(NOTE: Such ducts or pipes, if used, must have ample section and be so arranged as to furnish the specified volume of air to the machine, otherwise the ventilation will not be sufficient.)

**Enclosed separately ventilated machine.** An enclosed separately ventilated machine is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means external to and not a part of the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet duct pipes may be connected to them.

**Totally enclosed machine.** A totally enclosed machine is a machine so enclosed as to prevent the exchange of air between the inside and outside of the case, but not sufficiently enclosed to be termed air-tight.

**Totally enclosed fan-cooled machine.** A totally enclosed fan-cooled machine is a totally enclosed machine equipped for exterior cooling by means of a fan or fans, integral with the machine but external to the enclosing parts.

## SECTION 8—ENCLOSURE

**Protected machine.** A protected machine is a machine in which all ventilating openings in the frame are protected with wire screens, expanded metal or perforated covers, the openings in which do not exceed ½ square inch in area and are of such shape as not to permit the passage of a rod larger than ½ inch in diameter; except where the distance of exposed live parts from the guard is more than four inches, the openings may be ¾ square inch in area and must be of such shape as not to permit the passage of a rod larger than ¾ inch in diameter.

**Semiprotected machine.** A semiprotected machine is a machine in which part of the ventilating openings in the frame, usually in the top half are protected as in the case of a "Protected Machine," but the others are left open.

**Drip-proof machine.** A drip-proof machine is a machine in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine at any angle not greater than 15 deg. from the vertical, cannot enter the machine either directly, or by striking and running along a horizontal or inwardly inclined surface.

**Splash-proof machine.** A splash-proof machine is a machine in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine or coming towards it in a straight line at any angle not greater than 100 deg. from the vertical cannot enter the machine either directly or by striking and running along a surface.

**Water-proof machine.** A water-proof machine is a totally enclosed machine so constructed that a stream of water from a hose (not less than 1 inch in diameter) under a head of 35 feet and from a distance of about 10 feet can be played on the machine without leakage, except that leakage which may occur around the shaft may be considered permissible, provided it is prevented from entering the oil reservoir and provision is made for automatically draining the machine. The machine should be provided with a check valve for drainage or a tapped hole at the lowest part of the frame which will serve for application of drain pipe or drain plug.

**Submersible machine.** A submersible machine is a machine so constructed that it will operate successfully when submerged in water under specified conditions of pressure and time.

**Explosion-proof equipment.** Explosion-proof equipment is equipment in an enclosing case which is designed and constructed to withstand an explosion of a specified gas or dust which may occur within it, and to prevent the ignition of the specified gas or dust surrounding the machine by sparks, flashes or explosions of the specified gas or dust, which may occur within the machine casing. (NOTE: Explosion-proof equipment should carry the approval of the U. S. Bureau of Mines, or a recognized testing laboratory.)

## SECTION 9—KINDS OF TORQUE

**Locked rotor torque.** The locked rotor torque of a motor is the minimum torque which it will develop at rest for all angular positions of the rotor, with rated voltage applied at rated frequency.

**Pull-out torque.** The pull-out torque of a synchronous motor is the maximum sustained torque which the motor will develop at synchronous speed for one minute, with rated voltage applied at rated frequency and with normal excitation.

**Break-down torque.** The break-down torque of a motor is the maximum torque which it will develop with rated voltage applied at rated frequency, without an abrupt drop in speed.

**Torque margin.** The torque margin of a propulsion system is the increase in torque above rated torque to which the system may be subjected without the motor pulling out of step with the generator.

## SECTION 10—DUTY CLASSIFICATION

**Continuous duty.** Continuous duty is a requirement of service that demands operation at a substantially constant load for an indefinitely long time.

**Intermittent duty.** Intermittent duty is a requirement of service that demands operation for alternate periods of (1) load and no load; or (2) load and rest; or (3) load, no load and rest.

## SECTION 11—CONTROL APPARATUS

**Controller.** A controller is a device, or group of devices, which serves to govern, in some predetermined manner the electric power delivered to the apparatus to which it is connected.

**Full magnetic controller.** A full magnetic controller is an electric controller having all of its basic functions performed by electro-magnets.

By "basic functions" is usually meant acceleration, retardation, line closing, reversing, etc.

**Semi-magnetic controller.** A semi-magnetic controller is a controller having part of its basic functions performed by electro-magnets and part by other means.

**Manual controller.** A manual controller is a controller operated by hand.

**Drum controller.** A drum controller is a controller which utilizes a drum switch as the main switching element. The contacts of the main switching element are generally connected directly to resistors.

**Starter.** A starter is a controller designed for accelerating a motor to normal speed in one direction of rotation. (A device designed for starting a motor in either direction of rotation includes the additional function of reversing and should be designated a controller.)

**Automatic starter.** An automatic starter is a starter designed to automatically control the acceleration of a motor during the acceleration period.

**Auto-transformer starter.** An auto-transformer starter is a starter having an auto-transformer to furnish a reduced voltage for starting. The device includes the necessary switching mechanism and is frequently called a compensator or auto-starter.

**Across-the-line starter.** An across-the-line starter is a device which connects the motor to the supply without the use of a resistance or auto-transformer to reduce the voltage. It may consist of a manually operated switch or a master switch which energizes an electro-magnetic operated contactor.

**Master switch.** A master switch is a switch which serves to govern the operation of other switches. (Other switches usually consist of electro-magnetic operated contactors.)

**Resistor.** A resistor is a device used primarily because it possesses the property of electrical resistance. A resistor as used in electric circuits for purposes of operation, protection or control, commonly consists of an aggregation of units. (Resistors, as commonly supplied, consist of wire, metal ribbon, cast metal or carbon compounds supported by or imbedded in an insulating medium. The insulating medium may enclose and support the resistance material, as in the case of the porcelain tube type or the insulation may be provided only at the points of support, as in the case of heavy duty ribbon of cast iron grids mounted in metal frames.)

**Drip-proof control apparatus.** Drip-proof control apparatus is apparatus so protected as to exclude falling moisture or dirt. Drip-proof apparatus may be semi-enclosed apparatus if it is provided with suitable protection integral with the apparatus, or so enclosed as to exclude effectively falling liquid and solid materials from any angle up to 30 degrees from the vertical.

**Water-proof control apparatus.** Water-proof control apparatus is apparatus so constructed that a stream of water from a hose (not less than 1 in. in diameter) under a head of about 35 ft. and from a distance of about 10 ft. can be played on the apparatus without leakage.

**Weather-proof control apparatus.** Weather-proof control apparatus is apparatus so constructed or protected that exposure to the weather will not interfere with its successful operation.

**Submersible control apparatus.** Submersible control apparatus is apparatus so constructed that it will operate successfully when submerged in water under specified conditions of pressure and time.

**Explosion-proof control apparatus.** For explosion-proof control apparatus see Section 8.

**Overload protection.** Overload protection is the effect of a device operative on excessive current, but not necessarily on short-circuit, to cause and maintain the interruption of current flow to the device governed.

**Undervoltage protection.** Undervoltage protection is the effect of a device operative on the reduction or failure of voltage, to cause and maintain the interruption of power to the main circuit.

**Undervoltage release.** Undervoltage release is the effect of a device operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit but not to prevent the re-establishment of the main circuit on return of voltage.

**Constant torque resistor.** A constant torque resistor is a resistor for use in the armature or rotor circuit of a motor in which the current remains practically constant throughout the entire speed range.

**Fan duty resistor.** A fan duty resistor is a resistor for use in the armature or rotor circuit of a motor in which the current is approximately proportional to the speed of the motor.

**Overload relay.** An overload relay is an over-current relay in the circuit of a motor which functions at a predetermined value of the current to cause the disconnection of the motor from the line.

**Step-back relay.** A step-back relay is a relay which operates to limit the current peaks of a motor when the armature or line current increases. A step-back relay may, in addition, operate to remove the cause of the limitation to the current peaks of a motor when the armature or line current decreases.

## SECTION 12—CLASSES OF INSULATING MATERIAL[1]

**Class O insulation.** Class O insulation consists of cotton, silk, paper and similar organic materials when neither impregnated[2] nor immersed in a liquid dielectric.

**Class A insulation.** Class A insulation consists of: (1) cotton, silk, paper, and similar organic materials when neither impregnated[2] or immersed in a liquid dielectric; (2) molded and laminated materials with cellulose filler, phenolic resins and other resins of similar properties; (3) films and sheets of cellulose acetate and other cellulose derivatives of similar properties; and (4) varnishes (enamel) as applied to conductors.

**Class B insulation.** Class B insulation consists of mica, asbestos, fiber glass and similar inorganic materials in built-up form with organic binding substances. A small proportion of Class A materials may be used for structural purposes only.[3]

**Class C insulation.** Class C insulation consists entirely of mica, porcelain, glass, quartz and similar inorganic materials.

**Porcelain insulation.** Porcelain should not be used for lamp sockets, switches, receptacles, fuse blocks, terminal blocks, etc., where the material may be rigidly fastened by machine screws or the equivalent.

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[1] From "Introduction to A.I.E.E. Standards" (A.I.E.E. No. 1).

[2] An insulation is considered to be "impregnated" when a suitable substance replaces the air between its fibers, even if this substance does not completely fill the spaces between the insulated conductors. The impregnating substances in order to be considered suitable, must have good insulating properties; must entirely cover the fibers and render them adherent to each other and to the conductor; must not produce interstices within itself as a consequence of evaporation of the solvent or through any other cause; must not flow during the operation of the machine at full working load or at the temperature limit specified; and must not unduly deteriorate under prolonged action of heat.

[3] The electrical and mechanical properties of the insulated winding must not be impaired by application of the temperature permitted for Class B material. (The word "impair" is here used in the sense of causing any change which could disqualify the insulating material for continuous service.) The temperature endurance of different Class B insulation assemblies varies over a considerable range, in accordance with the percentage of Class A materials employed, and the degree of dependence placed on the organic binder for maintaining the structural integrity of the insulation.

## SECTION 13—TYPES OF CIRCUITS

**Lighting circuits.** Circuits for supplying lamps for illumination. They may supply current for propeller, portable, desk or bracket fans; heating appliances; motors of ¼ HP and less and other apparatus of not over 660 watts each.

**Heating circuits.** Circuits for supplying electric, air and liquid heaters, but not for lamps other than indicating for the heaters. Portable heating appliances of not over 660 watts may be connected to lighting circuits provided the rating of the circuit is not exceeded.

**Power circuits.** Circuits for supplying motors and cooking appliances, which are not permitted on lighting circuits, but not for lamps other than indicating for the apparatus.

**Interior communication circuits.** Circuits and systems used for audible and visual signals and communication of information from one place to another.

**Feeder circuits.** That portion of the wiring system from the supply switchboard, or panelboard to a receiving switchboard, or panelboard.

**Branch circuit.** That portion of a wiring system extending beyond the final overcurrent device protecting the circuit. (A device not approved for branch circuit protection, such as a thermal cutout or motor overload protective device is not considered as the overcurrent device protecting the circuit.)

**Outlet.** A point on the wiring system at which current is taken to supply fixtures, lamps, heaters, motors and current consuming equipment generally.

**Lighting outlet.** An outlet intended for the direct connection of a lampholder or a lighting fixture.

**Receptacle outlet.** An outlet equipped with one or more receptacles, not of the screw-shell type, or provided with one or more points of attachment within one foot or less, intended to receive attachment plugs.

**Panelboard.** A single panel or a group of panel units designed for assembly in the form of a single panel, including busses and with or without switches and/or automatic overcurrent protective devices for the control of light, heat or power circuits of small individual as well as aggregate capacity, designed to be placed in a cabinet or cutout box placed in or against a bulkhead and accessible only from the front. A lighting panelboard is one used only for lighting circuits. A power panelboard is one used only for power circuits.

**Demand factor.** The demand factor of any system or part of a system is the ratio of the maximum demand of the system or part of a system to the total connected load of the system or of the part of the system under consideration.

## CALCULATION OF CURRENT, VOLTAGE AND RESISTANCE

**Ohm's law as applied to direct current.** Ohm's law is the basic law on which these calculations are made, and is discussed in the following.

It was found experimentally that the flow of current through a resistance is directly proportional to the voltage applied. This is expressed algebraically by the equation:

$$I = E/R$$

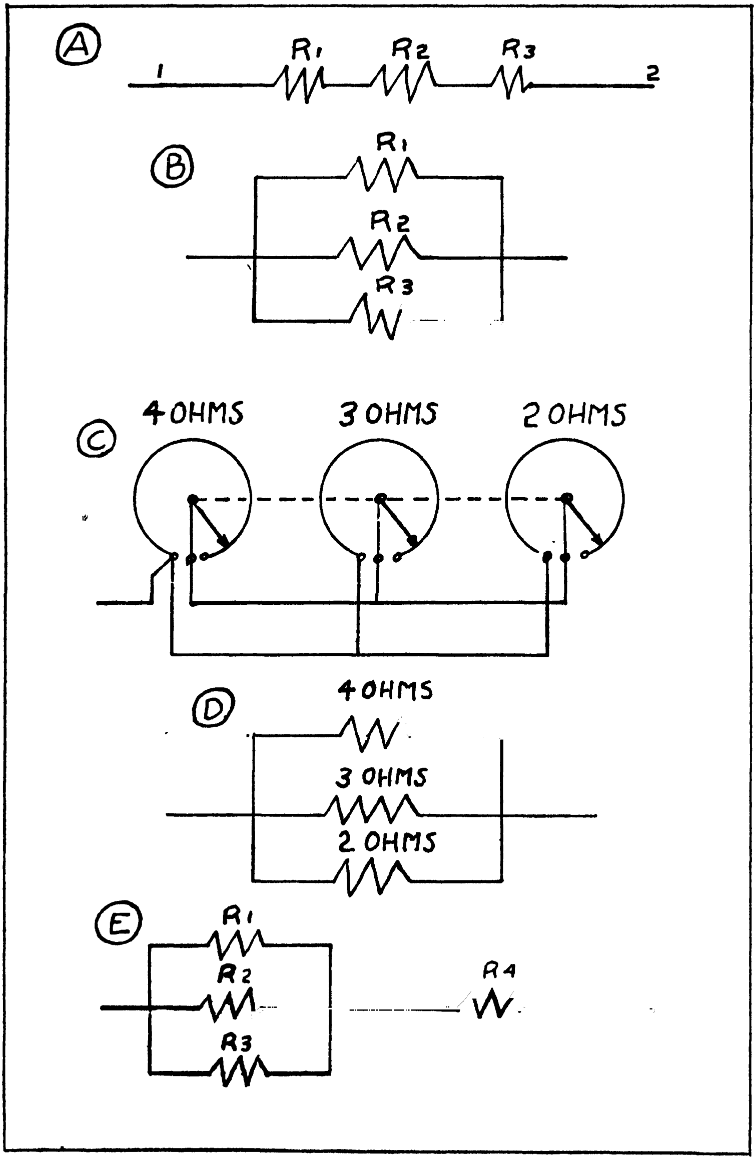
A
1
R1
R2
R3
2
B
R1
R2
R3
C
4 OHMS
3 OHMS
2 OHMS
D
4 OHMS
3 OHMS
2 OHMS
E
R1
R2
R3
R4

Fig. 2.

Where $I$ is the current, $E$ is the voltage and $R$ is resistance. By transposing these terms we have $E = IR$ and $R = E/I$.

The following examples illustrate the working of this equation.

1) Find the current $I$, when a voltage of 110 v. is applied to a resistance of 22 ohms.

$$I = E/R = 110/22 = 5 \text{ amps.}$$

2) Find the resistance when the current is 10 amps. and the applied voltage is 150 v. This may also be stated as: What is the resistance required to maintain a current of 10 amps. when a voltage of 150 v. is applied?

$$R = E/I = 150/10 = 15 \text{ ohms}$$

3) Having a 15-ohm resistance, what voltage is required to cause a current of 60 amps. to flow?

$$E = IR = 60 \times 15 = 900 \text{ v.}$$

It will be noted from the above that when any two quantities are known the third may be found.

The foregoing holds true for direct current and single phase alternating current (having resistance only such as in lighting and heating service).

**Calculations to determine resistance and reactance.** Where the value of a single resistor is required, no difficulty should be experienced. However, where a group of resistors are connected together, their arrangement has a direct bearing on the resultant resistance, and follows certain laws:

**Resistors in series** are shown in Fig. 2 A. Total resistance between points 1 and 2: $R \text{ (total)} = R_1 + R_2 + R_3$.

This may be stated: The total resistance $R$ equals the sum of the individual resistances.

Example. Find the resistance of the grids whose valves equal 2 ohms, 3.7 ohms and .98 ohms when connected in series.

$$R = 2 + 3.7 + .98 = 6.68 \text{ ohms}$$

**Resistors in parallel** (Fig. 2 B).

$1/R \text{ (total)} = 1/R_1 + 1/R_2 + 1/R_3$ or $R = 1 \div (1/R_1 + 1/R_2 + 1/R_3)$ and may be stated: The reciprocal of the sum is equal to the sum of the reciprocals of the individual resistors.

For 2 resistors, this method may be reduced to the product of the 2 resistors divided by their sum or:

$$R \text{ (total)} = R_1R_2 \div (R_1 + R_2)$$

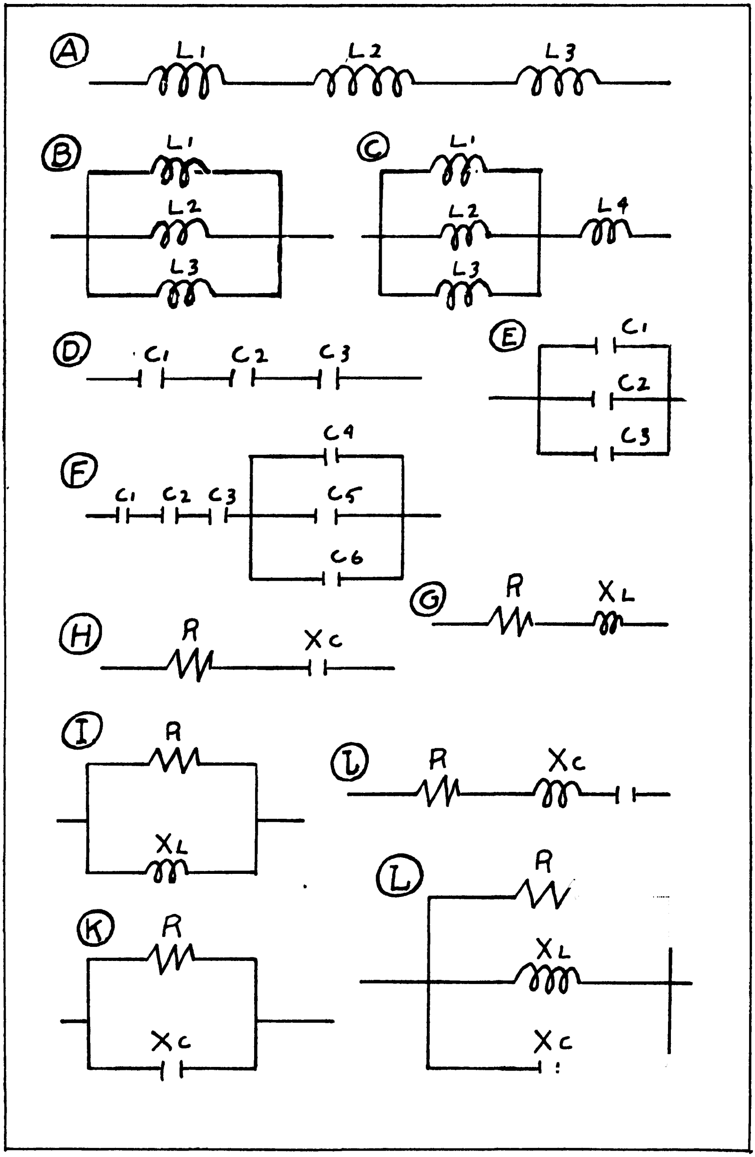
A
L1
L2
L3
B
L1
L2
L3
C
L1
L2
L3
L4
D
C1
C2
C3
E
C1
C2
C3
C4
F
C1
C2
C3
C5
C6
G
R
XL
H
R
XC
I
R
XL
J
R
XC
L
R
XL
XC
K
R
XC

FIG. 3

When using the reciprocal method the actual reciprocals may be taken from tables found in any standard handbook.

Example. Three sections of a rheostat are 4 ohms, 3 ohms and 2 ohms respectively (Fig. 2 C).

Find their maximum effective resistance in parallel. (Refer to the circuit diagram in Fig. 2 D.)

$$\begin{aligned} 1/R &= 1/4 + 1/3 + 1/2 \\ &= .25 + .333 + .5 \\ &= 1.083 \\ R &= 1/1.083 = .923 \text{ ohms} \end{aligned}$$

**Resistors in series-parallel** are shown in Fig. 2 E The method of solving this combination is to find the value of the parallel group ($R_1$, $R_2$, $R_3$) and add the result to $R_4$, which is in series. The total resistance is then:

$$R = 1 \div (1/R_1 + 1/R_2 + 1/R_3) + R_4$$

If again only 2 resistors are in the parallel group, the equation resolves itself into:

$$R = R_1R_2 \div (R_1 + R_2) + R_3$$

Here $R_1R_2$ are the resistors in the parallel group, in series with $R_3$.

**Inductances** in series, parallel and series-parallel follow the same laws as resistors. Referring to Fig. 3 A, the total inductance, $L = L_1 + L_2 + L_3$.

Referring to Fig. 3 B, the total inductive reactance $X_L = 2\pi fL$. $L = 1 \div (1/L_1 + 1/L_2 + 1/L_3)$.

Referring to Fig. 3 C, again total inductive reactance $X_L = 2\pi fL$. $L = 1 \div (1/L_1 + 1/L_2 + 1/L_3) + L_4$.

For **capacitance in series** (Fig. 3 D): $C = 1 \div (1/C_1 + 1/C_2 + 1/C_3)$

For **capacitance in parallel** (Fig. 3 E) · $C = C_1 + C_2 + C_3$

For **capacitance in series-parallel** (Fig. 3 F): $C = 1 \div [1/C_1 + 1/C_2 + 1/C_3 + 1/(C_4 + C_5 + C_6)]$

Inductive reactance, symbol $X_L$, and the impedance resulting from it follow the laws governing inductance in series and parallel, since: $X = 2\pi fL$, where $X_L$ = inductive reactance in ohms, $2\pi = 2 \times 3.1416$, $f$ = frequency in cycles per second, $L$ inductance in henrys.

Capacitive reactance, symbol $X_C$, and the impedance resulting from it follow the laws governing capacitance in series and parallel since:

$$X_C = 1 \div 2\pi fC,$$

where $X_C$ = capacitive reactance in ohms, $2\pi = 2 \times 3\,1416$, $f$ = frequency in cycles per second, $C$ = capacity in farads.

The following formulas give the impedance for different combinations of resistance, inductance and capacity.

1) Fig. 3 G. Resistance and inductive reactance in series: Total impedance $Z = \sqrt{R^2 + X_L^2}$ $X_L = 2\,\pi f L$

2) Fig. 3 H. Resistance and capacitive reactance in series: Total impedance $Z = \sqrt{R^2 + X_C^2}$ $X_C = 1 \div 2\,\pi f C$

3) Fig. 3 I. Resistance, inductive reactance and capacitive reactance in series: Total impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$ $(X_L - X_C)^2 = (2\,\pi f L - 1/2\,\pi f C)^2$

4) Fig. 3 J. Resistance and inductive reactance in parallel: Total impedance

$$\begin{aligned} Z &= 1 \div \sqrt{(1/R)^2 + (1/X_L)^2} \\ &= 1 \div \sqrt{(X_L^2 + R^2) \div R^2 X_L^2} \\ &= R X_L \div \sqrt{R^2 + X_L^2} \quad \text{ohms} \end{aligned}$$

5) Fig. 3 K. Resistance and capacitive reactance in parallel: Total impedance

$$\begin{aligned} Z &= 1 \div \sqrt{(1/R)^2 + (1/X_C)^2} \\ &= 1 \div \sqrt{(X_C^2 + R^2) \div R^2 X_C^2} \\ &= R X_C \div \sqrt{R^2 + X_C^2} \end{aligned}$$

6) Fig. 3 L. Resistance, inductive reactance and capacitive reactance in parallel: Total impedance $Z = 1 \div \sqrt{(1/R)^2 + (1/X_L - 1/X_C)^2}$

**Ohm's law as applied to alternating current.** Due to the reversal and the frequency of alternating voltage, the opposition to the flow of current by any circuit is quite different from that of direct current. This retardation of the current flow is known as reactance, and is due to the presence of inductance and capacity in the circuit, in addition to resistance, which is always present to a greater or less degree. The reactance due to inductance is known as inductive reactance, and is written $X_L$. The reactance due to the capacity in a circuit is called capacitive reactance, and is written $X_C$.

The inductive reactance $X_L$ is directly proportional to the frequency and also to the inductance. The capacitive reactance $X_C$ is inversely proportional to the frequency and also to the capacity.

The combined effect of resistance, inductive reactance and capacitive reactance is known as impedance, and is represented by the symbol $Z$.

When the impedance $Z$ is known, the operation of Ohm's law as applied to alternating current is similar to that when applied to direct current: that is, substituting $Z$ for $R$ we have:

$$I = E/Z,\ E = IZ \text{ and } Z = E/I,$$

where $I$ = amperes, $E$ = volts and $Z$ = impedance in ohms. Calculating current and voltage in alternating current circuits, when the resistance and reactance are known:

Resistance only (Fig. 4 A):

$$I = E/R \text{ and } E = IR$$

Resistance and capacitive reactance in series (Fig. 4 B):

$$I = E/Z = E \div \sqrt{R^2 + X_C^2}$$
$$E = IZ = I\sqrt{R^2 + X_C^2}$$

Resistance and inductive reactance in series (Fig. 4 C):

$$I = E/Z = E \div \sqrt{R^2 + X_L^2}$$
$$E = IZ = I\sqrt{R^2 + X_L^2}$$

Resistance, inductive reactance and capacitive reactance in series (Fig 4 D):

$$I = E/Z = E \div \sqrt{R^2 + (X_L - X_C)^2}$$
$$E = IZ = I\sqrt{R^2 + (X_L - X_C)^2}$$

Resistance and capacitive reactance in parallel (Fig. 4 E):

$$I = E/Z = E/RX_C \div \sqrt{R^2 + X_C^2}$$
$$E = IZ = I(RX_C \div \sqrt{R^2 + X_C^2})$$

Resistance and inductive reactance in parallel (Fig. 4 F):

$$I = E/Z = E/RX_L \div \sqrt{R^2 + X_L^2}$$
$$E = IZ = I(RX_L \div \sqrt{R^2 + X_L^2})$$

Resistance, inductive reactance and capacitive reactance in parallel (Fig. 4 G):

$$I = E/Z = E/RX_LX_C \div \sqrt{X_L^2X_C^2 + R^2(X_L - X_C)^2}$$
$$E = I(RX_LX_C \div \sqrt{X_L^2X_C^2 + R^2(X_L - X_C)^2})$$

## POWER

The unit of electric power is the watt, and is the product of the current and the voltage:

$$W = IE$$

where $W$ = watts, $I$ = amperes, and $E$ = volts.

Transposing, $I = W/E$ and $E = W/I$

since $E = IR$ (ohm's law)

$W = IE$ may be written $W = I \times IR = I^2R$

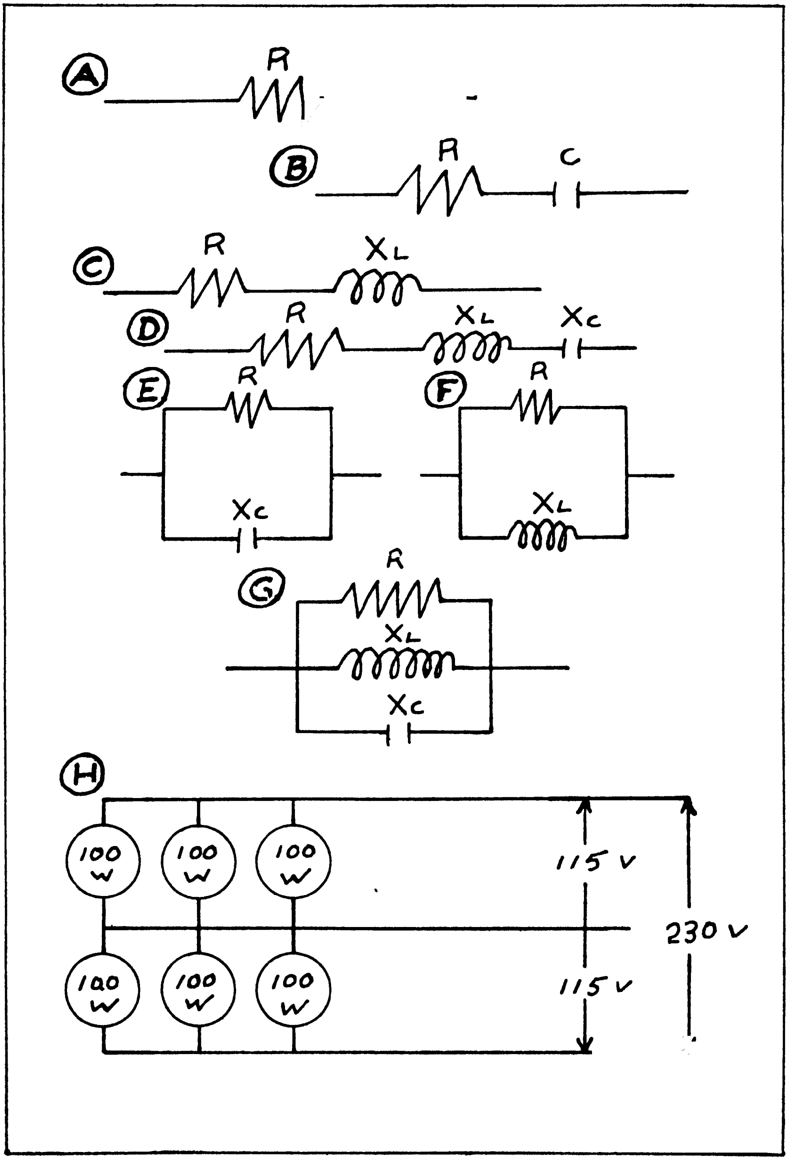
A
R
B
R
C
C
R
XL
D
R
XL
XC
E
R
XC
F
R
XL
G
R
XL
XC
H
100 W
100 W
100 W
100 W
100 W
100 W
115 V
115 V
230 V

FIG. 4.

This is often referred to as the $I^2R$ loss when considering the power dissipated by resistance.

The expression $W = EI$ may also be written as:

$$W = E^2/R \text{ (since } I = E/R)$$

This is convenient when voltage and resistance are known.

For the convenience of the reader the 3 forms are grouped together:

$$W = EI,\ W = I^2R,\ W = E^2/R$$

The current in a 2-wire direct current circuit is $I = W/E$, and in a 3-wire circuit is $I = W/2\,E$, where $E$ equals the voltage between the outside leads and neutral.

Example (see Fig. 4 H):

Load = 6-100-watt lamps = 600 watts on a 3-wire 115–230-v. system. Find the current in the outside leads.

$$I = W/2\,E = 600/2 \times 115 = 600/230$$
$$= 2.60 \text{ amps.}$$

The relation between horsepower. current voltage and wattage, and volt-amperes:

746 watts = 1 HP = 33,000 ft.-lbs. per min.

The table on p. 272 gives the relation between horsepower, current, voltage and volt-amperes for direct current, and single-phase, 2-phase and 3-phase alternating current.

The efficiency of a DC motor up to 30 HP is approximately equal to 83%, and above 30 HP approximately 88%.

The efficiency of a 3-phase induction motor up to 30 HP is approximately 75%, and above 30 HP 85%.

The efficiency of a synchronous motor at 100% power factor is about 93%.

**Selection of wire size.** The wire selected for a given device (motors, heaters, lights, etc.) must be capable of carrying the full load current without undue heating or loss in voltage (voltage drop). Table 1 shows the current carrying capacity of different size wires with different insulation. After a wire size has been selected for a given load, the voltage drop may be found by the following:

$$E \text{ (drop)} = (10.8 \times 2 \times L \times I) \div CM$$

where 10.8 = resistance in ohms of 1 mil-ft. of copper wire

$L$ = length of circuit (one way)

$I$ = current in amperes

$CM$ = circular mil size of wire

## TABLE 1

### WIRES AND CABLES
### MAXIMUM CURRENT CARRYING CAPACITIES DC FOR CONTINUOUS SERVICE

(Values are in amperes)

(Concentric stranding—600 volts or less—DC)

(AC cable ratings are the same as given for direct current up to 700,000 cir. mils.)

| CONDUCTOR SIZE | | | RUBBER INSULATED | | VARNISHED CAMBRIC INSULATED | |
|---|---|---|---|---|---|---|
| | | | *Continuous* | | *Continuous* | |
| *Area in Circular Mils* | *Gauge Nearest Awg Size* | *Area in Sq. In.* | 2 or 3 Conductors | Single | 2 or 3 Conductors | Single |
| 2,000,000 | | 1.5708 | | 1050 | | 1150 |
| 1,750,000 | | 1.3750 | | 940 | | 1040 |
| 1,500,000 | | 1.1781 | | 825 | | 955 |
| 1,250,000 | | 0.9820 | | 717 | | 830 |
| 1,000,000 | | 0.7854 | | 605 | | 725 |
| 950,000 | | 0.7460 | | 584 | | 700 |
| 900,000 | | 0.7070 | | 560 | | 674 |
| 850,000 | | 0.6680 | | 540 | | 647 |
| 800,000 | | 0.6283 | 415 | 515 | 455 | 618 |
| 750,000 | | 0.5890 | 390 | 492 | 435 | 592 |
| 700,000 | | 0.5505 | 370 | 470 | 413 | 563 |
| 650,000 | | 0.5100 | 350 | 441 | 392 | 530 |
| 600,000 | | 0.4715 | 330 | 418 | 371 | 501 |
| 550,000 | | 0.4325 | 310 | 395 | 350 | 474 |
| 500,000 | | 0.3922 | 290 | 370 | 327 | 444 |
| 450,000 | | 0.3535 | 270 | 345 | 308 | 414 |
| 400,000 | | 0.3148 | 250 | 319 | 284 | 383 |
| 350,000 | | 0.2745 | 228 | 292 | 256 | 350 |
| 300,000 | | 0.2356 | 208 | 263 | 234 | 316 |
| 250,000 | | 0.1969 | 180 | 233 | 203 | 280 |
| 212,000 | 0000 | 0.1659 | 160 | 209 | 182 | 251 |
| 168,000 | 000 | 0.1318 | 138 | 179 | 155 | 215 |
| 133,000 | 00 | 0.1045 | 120 | 153 | 133 | 184 |
| 106,000 | 0 | 0.0829 | 100 | 132 | 113 | 158 |
| 83,700 | 1 | 0.0658 | 87 | 112 | 98 | 134 |
| 66,400 | 2 | 0.0521 | 74 | 96 | 83 | 115 |
| 52,600 | 3 | 0.0414 | 66 | 82 | 74 | 98 |
| 41,700 | 4 | 0.0329 | 56 | 70 | 63 | 84 |
| 33,100 | 5 | 0.0261 | 48.5 | 60 | 54.5 | 72 |
| 26,300 | 6 | 0.0206 | 41 | 52 | 46.5 | 62 |
| 20,800 | 7 | 0.0163 | 35 | 44 | 39.5 | 53 |
| 16,500 | 8 | 0.0130 | 31 | 38 | 34.5 | 46 |
| 10,400 | 10 | 0.0082 | 23 | 28 | 25.5 | 34 |
| 6,530 | 12 | 0.0051 | 16.5 | 21 | 18.5 | 25 |
| 4,110 | 14 | 0.0032 | 11.5 | 15 | 13 | 18 |

**Note 1:** For voltages greater than 600 v., current rating should be decreased 2% for each thousand volts increase over 600 v.

**Note 2:** For varnished cambric insulated cables, the above values are based on an ambient temperature of 60° C. and a maximum conductor temperature not exceeding 85° C.

**Note 3:** For rubber insulated cables, the above values are based on an ambient temperature of 50° C. and a maximum conductor temperature of 75° C.

**Example.** A 230-v. DC, 50 HP motor takes a full load current of 180 amps., and is located 200 ft. from the generator. What is the voltage drop in the circuit?

At this point it might be added that the wire size selected in practice should have 25% more carrying capacity than the continuous current of the motor, to take care of starting currents.

$$180 \times 1.25 = 225$$

Referring to Table 1, a 300,000 CM-2/C-VC cable will carry 234 amps. Substituting this, the length and the current in the equation, we have:

$$\begin{aligned} E\ (\text{drop}) &= 10.8 \times 2 \times 200 \times 180 \div 300{,}000 \\ &= 2.592\ \text{v.} \end{aligned}$$

Approved practice calls for 3% drop on lighting circuits and 5% voltage drop on power circuits. The per cent drop is based on the generator voltage.

When working with a 3-wire 120–240 v. supply, the per cent calculations may be made as follows:

$$\begin{aligned} \%\ \text{drop} &= (10.8 \times 2 \times L \times I \times 100) \div CM \times 240 \\ &= (2160 \times L \times I) \div CM \times 240 \\ &= 9\,LI \div CM \end{aligned}$$

Substituting, we have:

$$\begin{aligned} \%\ \text{drop} &= (9 \times 200 \times 180) \div 300{,}000 \\ &= 1.08\%\ \text{drop.} \end{aligned}$$

Check: $240 \times .0108 = 2.592$

When using 120-v. supply for lighting, the per cent drop is:

$$\begin{aligned} \%\ \text{drop} &= (10.8 \times 2 \times L \times I \times 100) \div CM \times 120 \\ &= (2160 \times L \times I) \div CM \times 120 \\ &= 18\,LI \div CM \end{aligned}$$

It is common practice to use single conductor cables where the sizes are large — above #0-106,000 *CM*.

The current-carrying capacity of a conductor is based on the heat rise. Because of the heat resisting qualities of some insulation, some cables are rated higher than others of the same size. The carrying capacity of rubber insulated cables is based on an ambient temperature of 50° C. and a maximum conductor temperature of 75° C.

The carrying capacity of varnished cambric cable is based on an ambient temperature of 60° C. and a maximum conductor temperature of 85° C.

## POWER FACTOR CORRECTION

Low power factor increases the Kv-a. rating required in generating equipment, switchgear, lines, and transformers, and not only prevents the generation of maximum kw. but increases the losses in all current carrying parts, resulting in poor voltage regulation over the entire system. Various types of apparatus are available for improving power factor, but synchronous motors and static condensers have proven themselves to be most satisfactory. The synchronous motor, in addition to correcting power factor, may be used to carry a mechanical load. Static condensers have no moving parts, require no maintenance other than occasional inspection, and may be installed in out-of-the-way locations.

The best method of correcting power factor in a given case can only be determined by a careful study of surrounding conditions. Without taking into consideration special features, the amount of corrective Kv-a. may be determined as follows: *

$$\text{Present}\begin{cases}\text{(a)}\ \dfrac{KW}{\text{P.F.}} = KVA \\ \text{(b) Reactive } KVA = \sqrt{KVA^2 - KW^2}\end{cases}$$

$$\text{Desired}\begin{cases}\text{(c)}\ \dfrac{KW}{\text{P.F.}} = KVA \\ \text{(d) Reactive } KVA = \sqrt{KVA^2 - KW^2}\end{cases}$$

$$\text{(b)} - \text{(d)} = \text{Corrective } KVA \text{ required}$$

---

* See power factor scale Fig. 97.

# II

# LIGHT AND POWER

**Power supply.** Electric current may be either direct or alternating. The following voltages and systems of distribution are recognized as standard:

| | *Direct Current* | *Alternating Current* |
|---|---|---|
| Lighting . . . . . . . . . . . . | 115 volts | 115 volts |
| Power . . . . . . . . . . . . | 115 and 230 | 115–220–440 |
| Generators . . . . . . . . . . . | 120 and 240 | 120–230–450 |

**Standard frequency.** A frequency of 60 cycles per second is recognized as a standard for all alternating current light and power systems.

**Voltage and distribution systems (DC).** On vessels having little power apparatus, 120-volt generators are used with 115-volt light and power distribution systems. Where a large amount of power apparatus is provided, 240-volt generators, 230-volt power and 115–230-volt 3-wire lighting distribution systems are used.

**Voltage and distribution systems (AC).** For small vessels having little power apparatus, 3-phase 120-volt generators are used with the 115-volt lighting and power distribution systems. For vessels requiring considerable power apparatus, 3-phase 230-volt generators are in use with 3-phase 220-volt distribution for the power system and 115-volt single-phase 2-wire or 115–230-volt 3-wire single-phase transformers for distribution to the lighting system. Each of the 3 single phases have about the same load, so the currents will be about equal in each phase wire at the point where the 3 single-phase systems are joined into one 3-phase system. On very large vessels with a large amount of power, 450-volt 3-phase generators with 440 volts or 220 volts for power distribution and 115 volts for the lighting system, as described for the 230-volt generator system, will be found in use.

## SWITCHBOARDS

The function of the switchboard (see Fig. 5) is the control and distribution of the generated current. The following is a typical modern marine installation.

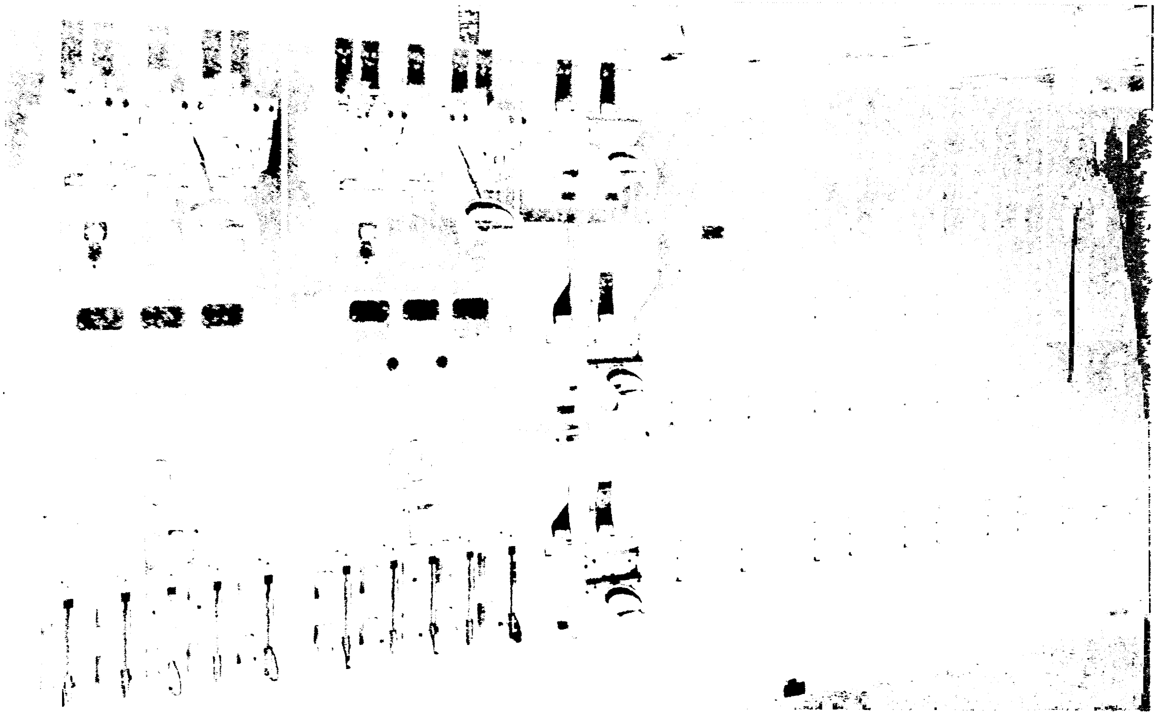

FIG 5 View of typical main switchboard

The board as a whole is composed of a non-combustible, non-absorbent insulating material, if live front, such as impregnated ebony asbestos lumber. The panels are usually not more than 36 inches wide and 84 inches high, and are commonly finished in dull black.

These panels are supported on angle iron framework and are very rugged. Strips of ⅛-in. rubber are often used between all non-metal parts and the upright steel. Two such strips ¼-in. thick are used between the bottom and the horizontal supports. This rubber should always be included when replacing panels after repair work and on new additions.

Switchboards are divided into two main parts—the generator panels, carrying the generator control equipment, and the feeder panels, carrying the feeder circuit breakers and power and light circuit switches.

The usual arrangement is to group the generator panels together at one end (the end nearest the generators). Next to these is the shore connection panel. Following this are the power panels and, finally, the lighting feeder panels.

Bus economy is the reason for this arrangement of panels.

**Generator panels.** Generator panels are for the control of the main generators, and are arranged to provide for quick interruption of the main generator circuits under overload conditions, and also in case of a reverse current.

A DC system using a 250-kw. 120–240-v. compound wound 3-wire generator would require either a 3-pole or a 5-pole circuit breaker, breaking positive, neutral, plus and minus equalizer and negative leads simultaneously, with a "trip free from handle." The number of poles depends on the circuit arrangement.

Although this generator delivers 1302 amps. at 25% overload, the circuit breaker will take 1600 amps., since this is the next largest commercial size.

The circuit breaker is the point at which the generator leads are connected to the switchboard; and in series with the circuit breaker and between circuit breaker and main bus is connected either a 3-pole or 5-pole disconnect switch.

The main circuit breaker mentioned above is provided with an inverse time limit over current trip and a reverse current trip. Some types of circuit breaker have an overload trip in the neutral.

An ammeter with a range of 0–1500 amperes, capable of reading the maximum overload current, is provided in both the positive and negative leads.

One voltmeter of 0–300-volt scale is provided, with a selector switch capable of reading both sides of neutral, full generator voltage, and voltage on any other generator feeding the main switchboard. A field rheostat is also provided, with its operating handle mounted at a convenient height.

A pilot lamp provides illumination for restoration of service in case the breaker trips.

One such panel as described is provided for each generator.

Mounted on a separate instrument panel or distributed over the existing generator panels are: A 0–300-volt calibrating voltmeter, arranged with a multi-position switch to read shore connection voltages and voltages on each generator, from positive, negative or neutral bus to ground; also a means for opening the neutral bus grounding circuit; an ammeter having a 50–0–50 scale for the neutral bus grounding circuit; a lamp ground detector for the 120–240-volt 3 wire generator bus; and a pushbutton to operate the neutral bus grounding circuit, which usually has a solenoid-opened spring-closed contactor.

In the rear of the generator panels are the positive, negative, neutral and equalizing busses.

The positive, negative and neutral busses are extended the full length of the board to all the feeder panels, from which run the various ship's circuits. These busses are made of 1/4-in. copper bar, 3 to 5 in. wide, and run in parallel where the current capacity requires it.

On ships having motor-generator sets, motor and generator panels may be included on the switchboard.

**Grounded neutral.** The latest method used in maritime practice for grounding the neutral of a 3-wire dual voltage 115–230-v. DC system is to connect the neutral bus solidly to ground at the main board through an ammeter shunt. The ammeter is of the "Center-Zero" type, having a full scale reading, plus and minus, of 150% of the neutral current rating of the largest generator. This arrangement indicates directly both the extent and the polarity of the ground.

This method has just been adopted at the time of writing, and a large number of ships will be found to have the following system:

The neutral bus is grounded through a resistor of such value that, when one side of the power system is grounded, either positive or negative, it will limit the neutral ground current to 1% of the total current of the power plant.

In normal operation this resistor is shorted out by an instantaneous type circuit breaker, which opens at 3% full load current. The resistor is then cut in. This system also has an alarm bell which operates when the circuit breaker opens, indicating an unbalance due to ground.

**Shore connection circuit breaker.** To facilitate receiving power from the shore, a 3-pole circuit breaker of about 600-amp. capacity, or more, is provided.

This circuit breaker, when closed, connects the main bus to the shore connection boxes generally located on the main or shelter decks. In this way the main board may be energized from a shore source. This is useful when it is necessary to have power when overhauling the main generators.

A remote possibility of using the shore connection is to feed power ashore or to another ship tied up alongside.

**Feeder panels (heavy types).** These panels carry the circuit breakers which protect the various feeders. The circuit breakers are for the most part manually operated. Those above 600 amps. in capacity are of the instantaneous type, with an inyerse time limit over current trip attachment; those below 600 amps. are the thermal overload trip type.

These thermal type circuit breakers will be found in 50, 100, 225 and 600 amp. frame sizes, having trip elements 15, 20, 25, 35, 50, 70, 90, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400, 450, 500, 525, 550, 600.

The circuit breakers trip free from the operating handle. They cannot be held in the closed position with an overload on the circuit.

Overload tripping is initiated by a bimetallic thermal strip, which when heated by over current deflects and releases the opening mechanism.

The thermal strip has an inherent time lag inversely proportional to the overload current. A short circuit causes almost instantaneous tripping. The large size circuit breakers over 600-amp. rating have an instantaneous magnetic trip.

The thermal type of circuit breaker is designed for the protection of light and power circuits which use rubber insulated wire, and is designed on the basis of the heat rise limit of this type of insulation.

The circuit breaker tripping elements are rated in accordance with commercial carrying capacities of the wire, according to the latest A.I.E.E. marine standards.

The rubber insulation will only stand a certain temperature rise, and the circuit breaker is designed to trip out before that point is reached. New synthetic rubber is rated at an ambient temp. of 75° C.

Any thermal device is inherently influenced by various ambient temperatures, and the relation of the temperature to its operation must be taken into account when determining its calibration.

All thermal devices have a certain temperature rise on their thermal element. This temperature rise must also be taken into account when determining their calibration. The present design is built around an ambient temperature of 23.9° C. or 75° F., and up to 40° C. or 104° F., at which temperatures these circuit breakers are not seriously affected. But above 50° C. (122° F.) ambient temperature the circuit breaker should not be loaded over 80%, and at 60° C. ambient not over 40%.

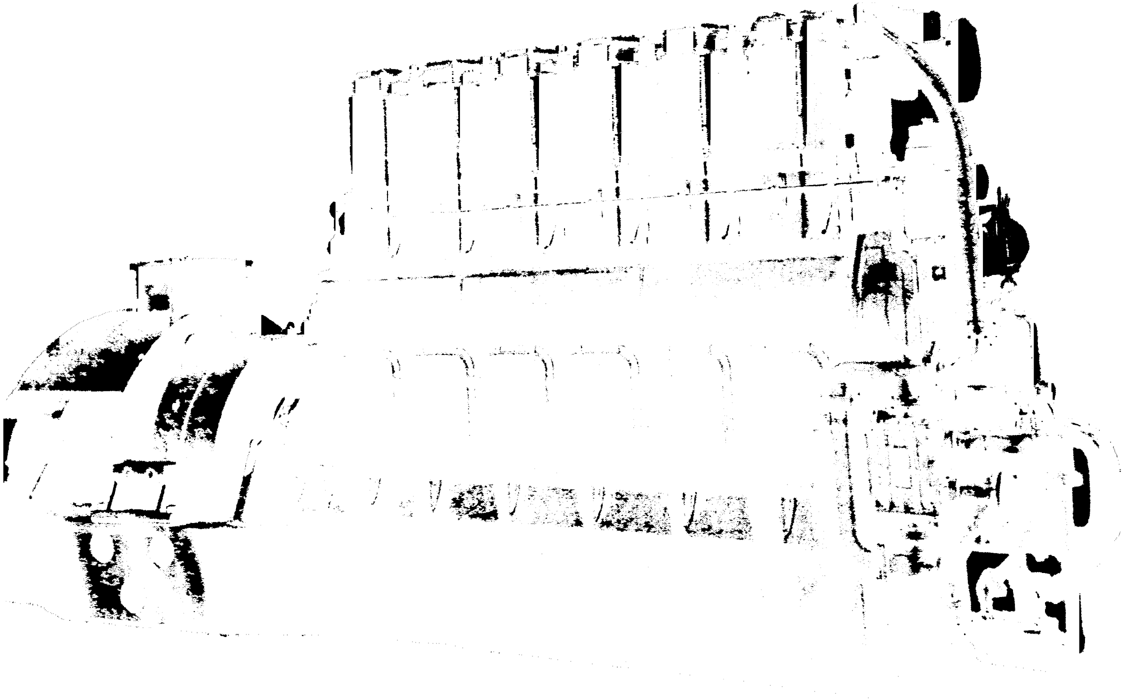

Fig 6 Diesel auxiliary electric generator set

An ambient temperature of 60° C. (140° F.) is unusual, but may occur in special cases.

## EMERGENCY LIGHT AND POWER SYSTEMS

**Emergency generators.** Emergency generators are commonly of the DC compound wound class, and are connected so as to take over the necessary circuits in case of failure of the main generators.

In modern installations emergency generators are usually located above the bulkhead deck, and quite often on the boat deck. Some passenger ships have their emergency generator rooms in the dummy funnel. Fig. 6 shows a Diesel auxiliary generator set.

In the following pages emergency generators, main-emergency power transfer systems and typical wiring diagrams and schematic arrangements will be illustrated and discussed.

The wiring diagrams are representative of the systems being installed on modern Maritime Commission ships. It is felt that they will serve as a guide to the electrician who has never been shipmates with such installations

**Emergency switchboard.** This is generally located on the boat deck and near the emergency generator set.

The emergency load is composed of the following:

Navigating equipment and running lights
Machinery space lighting
Radio room emergency equipment and lighting
Passageway lighting and exit lights
Quarters lighting and boat deck lighting
Galley, pantry, steering gear room
Emergency generator room
Chart room, pilot house
Gage boards, gage glasses, etc.
Communication circuits, engine order and steering telegraphs (if electric)
General alarm and fire alarm
Emergency loud speaker system
Emergency bilge and fire pumps
Lifeboat gear and flood lights
Emergency radio transmitter batteries in lifeboats (battery charging)

Power is supplied to the emergency switchboard from the main board on normal operation, and from the Diesel driven emergency generator on emergency operation.

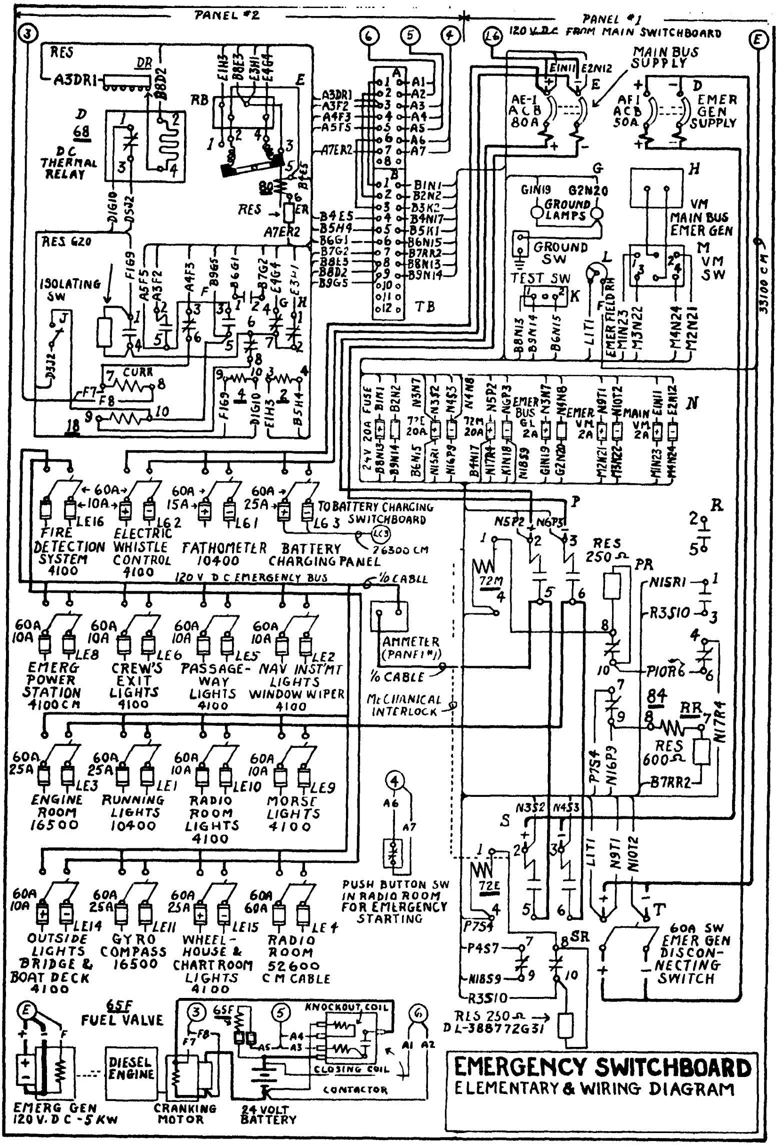
PANEL #2
PANEL #1
120 V.D.C. FROM MAIN SWITCHBOARD
MAIN BUS SUPPLY
AE-1 ACB 80A
AF1 ACB 50A
EMER GEN SUPPLY
E1N11
E2N12
RES
DR
A3DR1
B8D2
D 68 DC THERMAL RELAY
RB
E1H3
B8E3
E3H1
E4G4
A3DR1
A3F2
A4F3
A5F5
A7ER2
80
B4E5
RES
ER
A7ER2
B4E5
B5H4
B6G1
B7G2
B8E3
B8D2
B9G5
A1
A2
A3
A4
A5
A6
A7
B1N1
B2N2
B3K2
B4N17
B5K1
B6N15
B7RR2
B8N13
B9N14
TB
G
G1N19
G2N20
GROUND LAMPS
GROUND SW
TEST SW
K
L
H
VM MAIN BUS EMER GEN
M VM SW
B8N13
B9N14
B6N15
L1T1
EMER FIELD RH
M1N23
M3N22
M4N24
M2N21
33100 CM
RES 620
ISOLATING SW
J
F1G9
A5F5
A3F2
A4F3
B9G5
B6G1
B7G2
E4G4
E3H1
F
G
H
CURR
F7
F8
18
F1G9
D1G10
E1H3
B5H4
D3J2
D1G10
D5J2
N
24V 20A FUSE
B1N1
B2N2
N3N7
N3F2
N4S3
N4N8
77E 20A
72M 20A
N5P2
N6P3
EMER BUS GL 2A
EMER VM 2A
MAIN VM 2A
N3N7
N4N8
N9T1
N10T2
E1N11
E2N12
B8N13
B9N14
B6N15
N15R1
N16P9
B4N17
N17R4
K1N18
N18S9
G1N19
G2N20
M2N21
M3N22
M1N23
M4N24
60A 10A
FIRE DETECTION SYSTEM 4100
LE16
60A 10A
ELECTRIC WHISTLE CONTROL 4100
L62
60A 15A
FATHOMETER 10400
L61
60A 25A
BATTERY CHARGING PANEL
L63
TO BATTERY CHARGING SWITCHBOARD
LC3
76300 CM
120 V D C EMERGENCY BUS
½ CABLE
60A 10A
EMERG POWER STATION 4100 CM
LE8
60A 10A
CREW'S EXIT LIGHTS 4100
LE6
60A 10A
PASSAGE-WAY LIGHTS 4100
LE5
60A 10A
NAV INST'MT LIGHTS WINDOW WIPER 4100
LE2
AMMETER (PANEL #1)
½ CABLE
MECHANICAL INTERLOCK
60A 25A
ENGINE ROOM 16500
LE3
60A 25A
RUNNING LIGHTS 10400
LE1
60A 10A
RADIO ROOM LIGHTS 4100
LE10
60A 10A
MORSE LIGHTS 4100
LE9
A6
A7
PUSH BUTTON SW IN RADIO ROOM FOR EMERGENCY STARTING
60A 10A
OUTSIDE LIGHTS BRIDGE & BOAT DECK 4100
LE14
60A 25A
GYRO COMPASS 16500
LE11
60A 25A
WHEEL-HOUSE & CHARTROOM LIGHTS 4100
LE15
60A 60A
RADIO ROOM 52600 CM CABLE
LE4
P
N5P2
N6P3
72M
RES 250Ω
PR
N15R1
R3S10
P10R6
84
RR
RES 600Ω
N17R4
B7RR2
P7S4
N16P9
R
S
N3S2
N4S3
72E
L1T1
N9T1
N10T2
T
P7S4
P4S7
N18S9
R3S10
SR
RES 250Ω DL-388772G31
60A SW EMER GEN DISCONNECTING SWITCH
65F FUEL VALVE
DIESEL ENGINE
EMERG GEN 120 V.D.C. - 5 KW
CRANKING MOTOR
24 VOLT BATTERY
KNOCKOUT COIL
CLOSING COIL
CONTACTOR
F7
F8
A4
A3
A5
A1
A2
EMERGENCY SWITCHBOARD
ELEMENTARY & WIRING DIAGRAM

FIG. 7.

**Emergency switchboard operation.** Switching and control equipment on the emergency generator panel consists of a 3-pole air circuit breaker, which is of the time limit overload type with reverse current and shunt trip features, a 3-pole unfused lever switch, a voltmeter, 2 ammeters, a generator field rheostat, a generator pilot lamp and other necessary equipment.

To energize the main switchboard bus from the emergency bus, for "dead ship cold boiler starting" (see page 42), snap switches are mounted on the rear of the emergency switchboard capable of rendering the electrical interlocks on the bus transfer panel inoperative, together with means for removing the mechanical interlock between the bus transfer contactors, permitting the reverse flow of power through the bus transfer main contactor. Also the supply to the main contactor solenoid must be changed from main generator to emergency generator circuit, to permit the closing electrically of the main contactor when main switchboard is dead.

In addition to the above provisions for dead ship cold boiler starting, emergency current may also be used for galley equipment when the emergency generator is connected to the main switchboard bus, by closing the galley circuit breaker at the main switchboard. To prevent use of unnecessary galley equipment, the fuses for galley units may be removed from the galley power panels.

**Operation of automatic bus transfer and Diesel starting circuit.** Refer to Fig. 7 for wiring diagram of a General Electric installation.

The purpose of this circuit is to automatically start a Diesel engine driven generator and transfer the emergency load from the main generators to the Diesel generator in case of voltage failure on the main bus.

Transfer is accomplished by means of a set of magnetic contactors located on the emergency generator board. The signal for transfer is given by a voltage relay, device 80, mounted on the emergency board.

When the main bus voltage drops to 100 volts or below, the voltage relay operates. Approximately three seconds later the Diesel cranking motor is energized, and if conditions are normal the Diesel should crank up to firing speed and start to operate. When sufficient voltage is available on the emergency bus the load is transferred from the main bus to the emergency bus. Upon restoration of voltage at 110 volts on the main bus the load will automatically retransfer to the main bus.

The emergency board is normally fed through a fused circuit from the main board and a circuit breaker on the emergency board. For greatest continuity of service this fused switch and circuit breaker should be closed at all times. If maintenance work is to be done on the board both switch and circuit breaker should be open.

The emergency generator is connected to the emergency bus through a disconnect switch and a circuit breaker. For greatest continuity of services these should be closed at all times unless maintenance work is to be done on the board.

The detail steps involved in the transfer from main to emergency generator are as follows:

1) When the main bus voltage drops to 100 volts or below a voltage relay, device 80, drops out.

2) When the voltage relay drops out it opens a contact 1–2, and de-energizes the coil circuit for device 2.

3) Device 2 drops out and closes its 1–2 contact. This energizes the potential coil of device 18 which picks up.

4) When device 18 picks up it closes its 1–4 contact and energizes device 4, which picks up and seals itself in through its 4–7 contact.

5) Device 4 performs two functions. It de-energizes the potential coil of device 18 and energizes the coils of devices 6 and 65F. Device 65F is a fuel oil valve which opens. Device 6 is a motor starting contactor which closes and starts the Diesel engine cranking.

6) When the potential coil of device 18 is de-energized, the relay is ready to drop out. However, this relay has a long time delay on dropout, and before the relay contacts actually open the current coil 7–8 is energized and holds the relay closed.

7) This current coil of device 18 is connected across the series field of the cranking motor and the current flowing through the relay coil depends upon the current flowing through the series field. When the motor starts to crank sufficient current is available to hold device 18.

8) When the Diesel engine starts to fire, the current through the cranking motor field decreases and there is no longer sufficient current to hold the relay closed. Inasmuch as the potential coil has already been de-energized, device 18 drops out. This de-energizes the cranking motor contactors and at the same time applies current to the knockout coil of device 6.

9) Device 6 opens and disconnects the cranking motor from the battery. The Diesel engine should now be running on its own power, and voltage should build up on the emergency generator.

10) When sufficient voltage is available on the emergency generator, device 84 picks up. This de-energizes the main service contactor which will drop out if it has not already done so, and close the emergency contactor. The load is now energized from the emergency generator.

11) If voltage should return on the main bus (110 V.) before the contactors operate to perform the transfer, device 80 and device 2 pick up. This de-energizes the coil of device 4, which drops out. When device 4 drops out, the fuel oil valve is de-energized and closes, shutting off the Diesel. Device 84 cannot pick up, and the load remains on the main generators.

12) If voltage should return on the main bus after transfer has taken place, the same sequence of operations follow. The fuel oil valve is shut off and device 84 is de-energized. When device 84 is de-energized it drops out, de-energizing the emergency contactor and re-energizing the main line contactor.

13) For test purposes a manually operated switch is provided to the switchboard and another switch in the radio room. If either of these switches is operated, it de-energizes the coil circuit of device 80 and the sequence of operation is performed as described above.

14) In order to prevent the Diesel engine from being started, if work is to be performed on the switchboard or on the engine, a manually operated isolating switch is provided on the switchboard. This switch should be always left in the closed position when automatic starting of the Diesel engine is required.

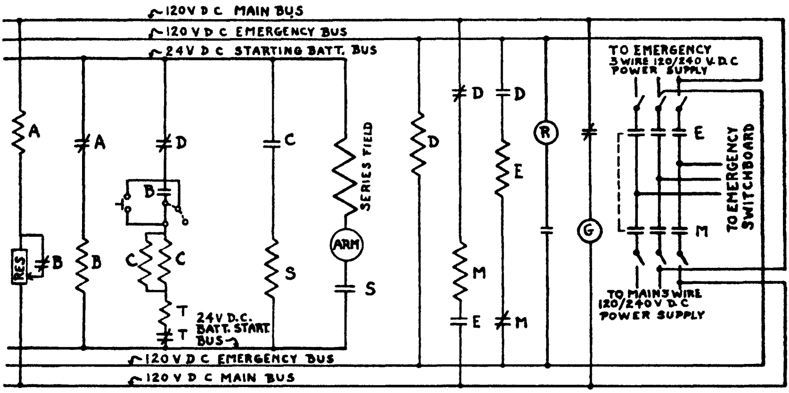

FIG. 8. Main emergency power transfer system—wiring diagram.

**Another main emergency power transfer system.** Referring to Fig. 8, the relays, coils and contactors are shown in the de-energized position

In normal operation the 120-v. DC main bus is energized. This causes coil **A** to be energized, which in turn holds open the **A** contact keeping the **B** coil de-energized.

The resistor in series with coil **A** is adjusted so that when the voltage on the 120-v DC main bus drops to 80% of normal (96 volts), contact **A** falls out and coil **B** is de-energized. This closes contact **B** and (when the "Automatic-on-off" switch is in the automatic position) coil **C** is energized. This in turn closes contact **C**, which energizes the closing coil **S**, which closes the starting contacts **S** in the starting battery circuit. This turns over the starting motor of the emergency generator Diesel engine.

If the Diesel engine does not start after a specified number of seconds, contact **T** of the timing circuit opens. This stops the starting motor. After a short period the timing circuit is re-established and the cycle is repeated indefinitely until the engine is started.

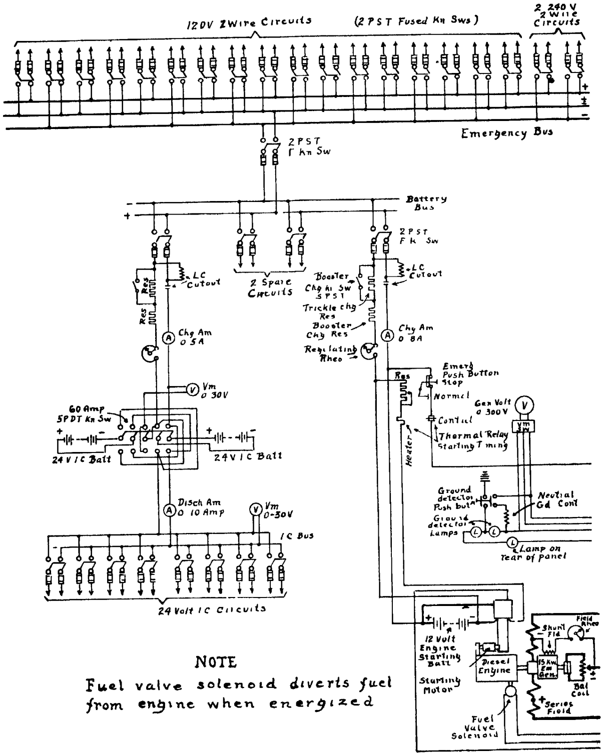

Fig 9A.

Fig. 9A. (opposite page) and Fig. 9B. (below) show a schematic diagram of another main-emergency power transfer hook-up. This system, with or without certain modifications, will be found on some of the Maritime Commission ships.

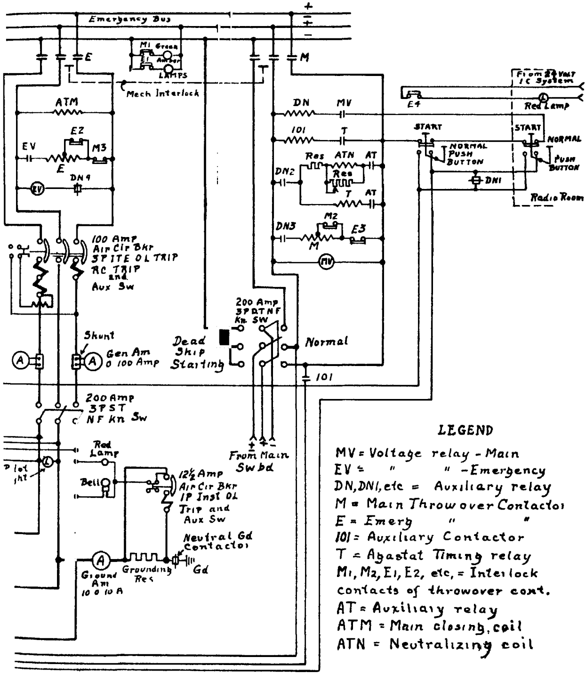

Fig 9B.

When the emergency generator comes up to speed and delivers full voltage to the 120-v. DC emergency generator bus, coil **D** is energized. The closed **D** contact in series with coil **M** opens, releasing the "main" contactor section of the main-emergency bus transfer and the open **D** contact in series with coil **E** closes energizing coil **E**, closing the "emergency" contactor of the main-emergency bus transfer and transferring the emergency switchboard to the emergency generator.

A mechanical interlock completes this transfer by opening the "main" contactors.

The closed **D** contacts in series with the **C** coil and the timing circuit (coil **T** and contact **T**) opens and stops the starting motor.

## DEAD SHIP STARTER (DIESEL-DRIVEN VESSELS)

The "dead ship starting" of Diesel-driven vessels is very similar to that of steam. The method of operation and the sequence to follow in starting is as follows:

1) Clear the main and emergency switchboards entirely.

2) Start the emergency generator and close the generator circuit breaker.

3) Energize the machinery space emergency lighting circuit.

4) Energize the 240-v. emergency to main switchboard bus tie feeder and the main switchboard 240-v. bus by closing the emergency main switchboard tie circuit breakers.

5) Start the forced draft blowers on the oil-fired section of the waste-heat boiler at slow speed, adjusting damper to obtain low pressure.

6) Shut off fuel oil service suction from the settling tank.

7) Open valve from Diesel fuel oil tank to suction side of fuel oil service pump.

8) Start fuel oil service pump at 75% speed.

9) Light off the burner.

10) When steam is available, turn on steam to one fuel oil heater and one settling tank.

11) When regular fuel oil in settling tank is properly heated, transfer from Diesel to bunker fuel.

12) Start ship's light and power Diesel generator set in the usual manner.

13) When Diesel generator set is capable of assuming load, trip main switchboard emergency bus tie feeder circuit breaker (closed in 4).

14) Trip emergency generator circuit breaker and stop emergency generator.

15) Clear emergency switchboard.

## DEAD SHIP COLD BOILER AND GENERATOR ENGINE STARTER (Steam-Driven Vessels)

The "dead ship cold boiler starting" system makes use of the 15 kw. (or more) 240/120–v., DC emergency generator for operating the fuel oil service pump and forced draft blower.

The method of operation and the sequence to be followed in starting a cold boiler follows:

1) Clear main emergency switchboard.

2) Start emergency generator and close circuit breaker, thus energizing the emergency switchboard bus.

3) Energize machinery space emergency lighting circuit.

4) Energize the 240-v. emergency to main switchboard bus tie feeder and the main switchboard 240-v. bus, by closing the emergency and main switchboard bus tie circuit breakers.

5) Start the forced draft blowers at slow speed, adjusting damper to obtain low pressure.

6) Start fuel oil service pump at about 75% speed.

7) Light off burner.

8) At 200 lb. boiler pressure, start generator turbine, exhausting to atmosphere.

9) When turbo-generator is capable of assuming load, trip the main switchboard emergency bus tie feeder circuit breaker (closed in 4) and instantly close turbo-generator circuit breaker.*

10) Trip emergency generator circuit breaker and stop emergency generator. Clear emergency switchboard.

## LIMITED GALLEY OPERATION FROM THE EMERGENCY GENERATOR

The emergency generator is usually arranged to supply current for a limited amount of galley equipment. In order that the galley may make use of the emergency current the switches on the emergency switchboard are operated as above for dead ship starting.

The galley is ready for operation when its circuit breaker on the main switchboard is closed. To prevent the use of unnecessary galley equipment the fuses in these circuits should be removed.

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* If the emergency generator circuit breaker located on the emergency switchboard is equipped with a reverse current trip, the main generator circuit breaker may be closed and the emergency generator circuit breaker will open as soon as the emergency generator begins to motor, i.e., to take current from the main bus. No vital auxiliaries will be lost during the transfer, since all these will have their starters arranged for "low voltage release."

# III

# GENERATORS

## DIRECT-CURRENT GENERATORS

The electric generator (Fig. 10) is a device for converting mechanical energy (supplied by a prime mover) into electrical energy. The generator is an induction machine, that is, it operates on the principle that when a conductor cuts a magnetic flux a voltage is induced in it and current will flow, providing that the conductor is connected to a closed circuit.

The flux is provided by north and south magnetic poles.

The conductors which cut the flux are in the form of coils disposed about a rotor known as an armature, and are so arranged as to make a continuous closed winding.

The north and south poles are so placed in relation to the armature as to cause a current to flow in the same direction in any one armature coil. This results in the voltages induced by the two poles being added. This is because when the winding of the coil changes direction it is always under a pole of opposite polarity. A close inspection of an armature will show this.

Interpoles or commutating poles are small poles placed midway between the main poles to induce a voltage in the coil being commutated which will aid in a quick reversal of the current in that coil, reducing the sparking to zero. The winding of the interpole field coil is made up of a few turns in series with the brushes, and is capable of carrying full load current.

**Commutation.** The generator brushes are placed at the neutral point, that is, the point midway between adjacent poles.

The current in the coils on either side of the brushes flows in the opposite direction. As the coils pass under the brushes a complete reversal must take place in the direction of current in those coils coming under the brushes. This reversal should be instantaneous, but could only be so with zero resistance in coil, brush and brush contact. Also, due to self-induction in the coil the reversing action of the current is further delayed, so that as the commutator bar leaves the brush sparking occurs. The resistance may be made low by correct size of copper, but high resistance (carbon) brushes are an advantage.

It might be added at this point that older machines may be encountered which do not have commutating poles, in which case the brushes are moved forward in the direction of rotation. DC generators, like DC motors, may be either shunt or compound wound.

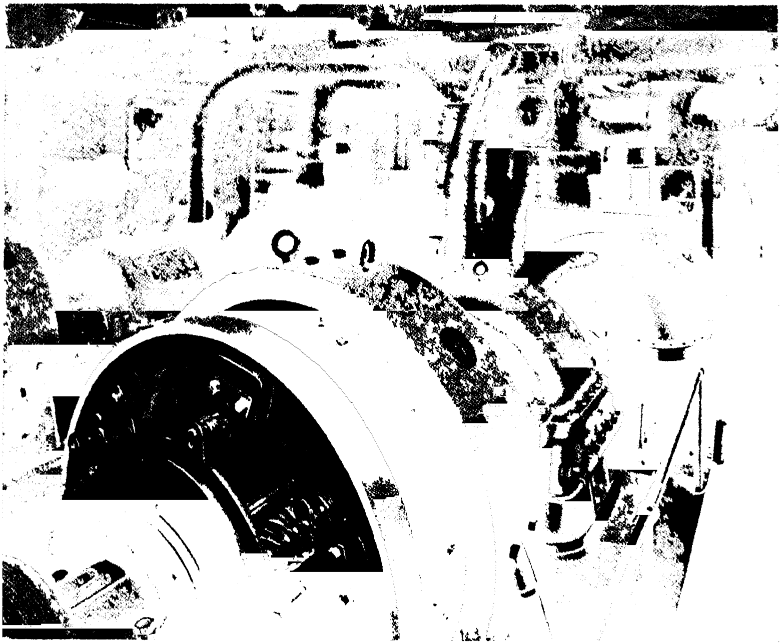


FIG 10. Auxiliary 3-wire 240-v. DC turbine generator set. Commutator end, showing brush rigging.

**Shunt wound generator.** The shunt wound generator has its field in parallel with its armature, and the voltage drops off considerably with increase in the load. To compensate for this undesirable feature a rheostat is placed in the field circuit. By varying the resistance of the field circuit the voltage may be maintained constant throughout the entire range of the load. This is accomplished as follows: if the load increases and the terminal voltage drops, some of the field resistance is cut out. This raises the field voltage and increases the excitation, which in turn raises the generator voltage, bringing it back to normal. Voltage regulators are used where constant voltage is considered imperative at all times. These will be discussed later.

**Compound wound generator.** The compound wound machine has a shunt field and a series field. The series winding is normally connected to aid the shunt winding, thus tending to increase the voltage as the load increases.

According to the ratio of the series field to the shunt field the generator is said to be of the over compound, flat compound or under compound type.

If the series field is connected so as to oppose the shunt field it is said to be differentially compounded.

In all the above degrees of compounding the voltage rises to its highest point at about ¾ full load, and drops off slightly at full load.

If a compound machine gives the same terminal voltage at full load as at no load it is said to be flat compounded, although the voltage rises between these two points.

The over compounded machine is flatter in its voltage characteristic from 60 to 125% full load than the others, but for a given full load terminal voltage it would have to have a "below normal" no load voltage.

The adjustment of the terminal voltage is accomplished by a shunt field rheostat similar to the shunt machine.

Although compound wound generators have desirable voltage characteristics they are unstable when operated in parallel. To overcome this instability they are arranged to operate with their armatures paralleled through an equalizer bus. This connection causes a division of the load between the machines in proportion to their rated capacity.

In modern DC installations will be found 3-wire, 120–240-volt DC generators supplying power to 115–230-volt systems. The third wire in this system is known as the neutral and it is required that the 115-volt lighting load connected between the outside and neutral, be balanced.

Although there are still some in existence, balancer sets are not recommended for obtaining 120 volts from the 240-volt, 2-wire DC generators.

The 3-wire generator referred to above is in effect a standard 2-wire generator with its armature tapped at two diametrically opposite points and connections brought out, through slip rings, to a compensator or balance coil. A center tap on this balance coil forms the neutral of the system.

Unless otherwise specified, all 3-wire, DC generators are designed for 25% unbalanced current.

**Prime movers.** Prime movers for generating sets are either turbine or reciprocating, the latter being either steam or Diesel. In modern practice, ships having steam propulsion equipment also are equipped with steam driven generators.

Diesel engines are now used almost exclusively for emergency generating sets.

In the case of moderately large and large plants and of small plants where load does not fluctuate much, shunt wound generators or special types of compound wound generators may be found in service instead of regular compound wound generators.

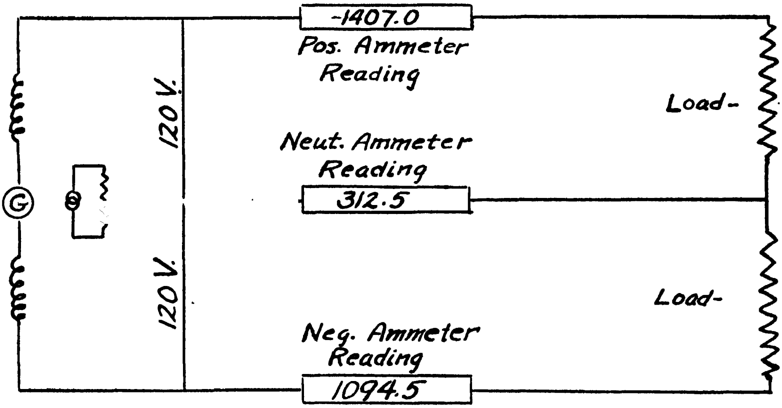


Fig. 11. Diagram of unbalanced current.

For economy and insurance against total disruption of service it is practical to install two small generators on a vessel instead of one large one. If one large machine were installed it should be capable of handling the entire ship's load. But in case of failure the entire ship's service would be out except those vital circuits taken over by the emergency set. (See Emergency Power Transfer System.) Consequently modern practice is to install two generators. When the ship's demand is greater than the capacity of a single machine the second machine is cut in and the two operated in parallel.

(For complete instructions for paralleling generators see Operation Section.)

In Fig. 12 is shown the connections of two 120–240-volt, 3-wire, compound wound, DC generators arranged for operation in parallel and stabilized by use of the equalizer system. This circuit employs 5-pole circuit breakers and 5-pole disconnect switches.

The equalizer leads 2 and 4 are connected at a point midway between

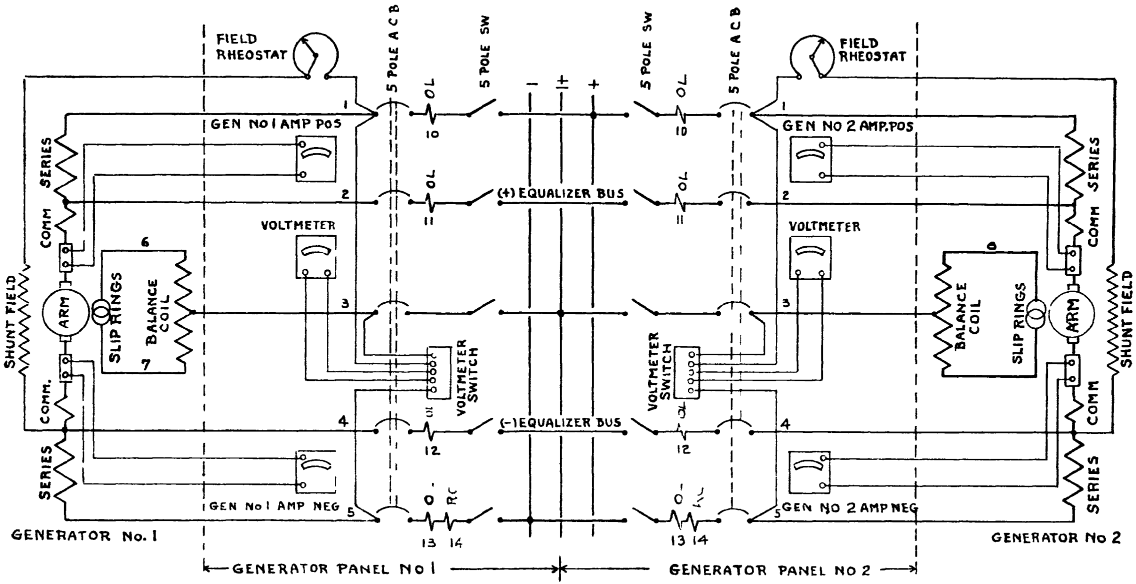


FIG. 12. Connections of two 120–240-v. 3-wire generators, arranged for operation in parallel.

the commutator coil and the series field coil. This arrangement puts the series coils of each generator in parallel. The total load current then passes through the two coils, divided in inverse proportion to their resistance. This means the machine with the lower resistance series field coil will take the greater current. Since the greater the kw. capacity of the generator, the lower the resistance of the series field winding, machines using the equalizer method, will share the load in direct proportion to their capacity: That is, the larger machine will take the greater load. Also, equal capacity machines will share the load equally.

It is necessary for good operation to make the equalizer leads of very low resistance in practice. On the larger capacity installations this lead is usually half the cross-section area of the outer mains (1 and 5).

The slip rings are connected internally on the machine to two points on the armature, 180° apart. Externally, through the brushes, the slip rings are connected through leads 6 and 7 to the outer ends of the balance coil, providing a path for the unbalanced current flowing in the neutral lead 3 back to the unbalanced side of the 3-wire system.

When the unbalance current, flowing in the neutral, reaches the center tap of the balance coil, it divides and goes both ways. Consequently the leads 6 and 7 are required to carry only half of the current of the neutral lead 3, and are therefore usually smaller.

The unbalance current referred to above is the current on one side of the 3-wire system in excess of the other. This excess current always returns to the generator through the neutral lead. Above is a diagram showing an unbalance current of 312.5 amperes on the positive side of a fully loaded 300-kw., 120–240-volt, DC generator. This represents an unbalance of 25%. The unbalance current flowing in the neutral = 1407 − 1094.5 = 312.5 amperes. (See Fig. 11.)

In practice a neutral ammeter is not used—only the difference in "positive" and "negative" amperes is noted. Three-wire generators are usually designed to handle 25% unbalance continuously and 25% overload for 2 hrs.

The balance coil is a center tapped reactance or autotransformer. It provides a means of connection (through the slip rings) to a mid point on the armature, and has sufficient reactance to the alternating currents which flow within the armature.

Referring again to Fig. 12 the shunt coil is connected across the mid point midway between the negative commutating coil and the negative series field coil and the generator side of the positive pole of the circuit breaker.

The shunt field control rheostat is in series with the shunt field, and

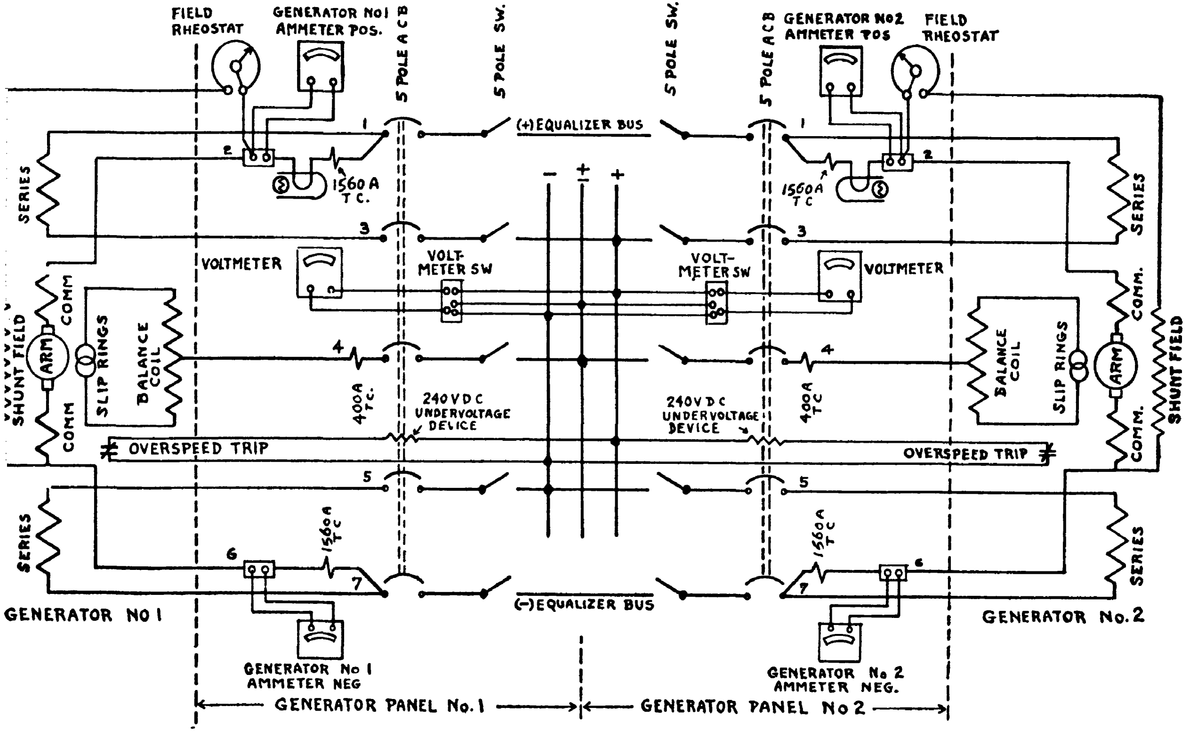


FIG. 13. Same as Fig. 12 except for the series field coil connections.

is used to control the load on the machine by controlling the output voltage.

One voltmeter is provided for each machine, with a voltmeter switch which permits the operator to read the voltage across the outer mains or from the positive or negative side to neutral.

An ammeter is provided for reading the current in the positive and negative mains 1 and 5. This indicates the amount of unbalance (difference in reading) at all times. The shunts for these instruments will be seen located between the commutator brushes and the commutating field coil. Referring again to the circuit breaker, the overload trip coils are located at points 10, 11, 12, and 13, and the reverse current trip coil at 14.

Fig. 13 shows the connections for two 120–240 volt, 3-wire, 300-kw., compound wound generators arranged for parallel operation, using the equalizer bus system for equalizing the load and producing stable operation of the generators. The circuit is quite similar to that shown in Fig. 12, except that both ends of the series field coils are brought out separately and connected as shown. The path of the main line current starting at the positive bus is as follows:

From the positive bus, through the disconnect switch, through the circuit breaker, to lead 3, through the positive series coil, lead 1, through the 1560-ampere overload trip coil, through the reverse current relay, the positive ammeter shunt through lead 2, and the positive commutating coil through the positive brush, through the armature, the negative brush, the negative commutating field, lead 6, to the negative ammeter shunt, the 1560-ampere overload trip coil, lead 7, the negative series field coil, lead 5, circuit breaker, disconnect switch and the negative bus.

The undervoltage device is connected across the 240-volt bus in series with the overspeed trip (used on turbine driven generators). This opens when the generator is overspeeded either by the turbine or by motoring and disconnects the machine from the line.

If the equalizer leads for some reason were opened one generator would begin to take all the load including driving the other as a motor.

The voltmeter, ammeters, balance coil and rheostat have the same function as in Fig. 12, and connections are generally the same.

Comparing Figs. 12 and 13, the practical advantage of Fig. 12 over Fig. 13 is that the connections used operate with lighter copper in the equalizer leads. In Fig. 13 the leads 1 and 2, 6 and 7, which make available the point at which the equalizer bus is connected, must carry the full load current. However, this arrangement allows the equalizer circuit to be of extremely low resistance, since it may be made up of a bus bar mounted on the switchboard.

## 500-KILOWATT GENERATORS

The following is a description of a 500-kw. 240-volt 3-wire DC generator manufactured by the Westinghouse Company.

As most DC generators and motors have much the same physical appearance and are constructed in much the same manner, this description will in a general way apply to all DC machines

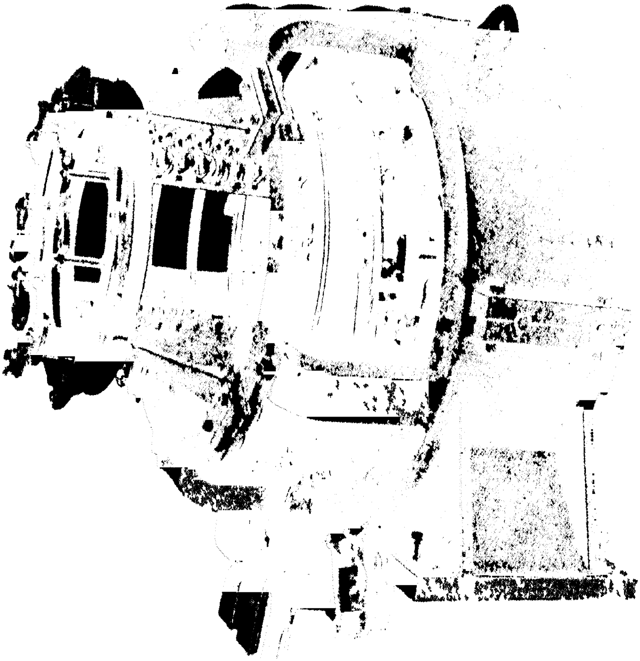


FIG 14 Stationary part of a 500-kw generator (Westinghouse).

This description shows the reader typical information such as he may expect to find in a manufacturer's instruction book. It should be kept in mind that the sizes and quantities are for this machine only.

**Rating.** The generator shown in Figs. 14 and 15 is compound wound, designed for a continuous rating of 500 kw, 240 volts, 1200 r.p.m., without exceeding 40° C. temperature rise by thermometer on insulated windings. The design also provides for carrying 125% full load current for 2 hours with a 55° C. temperature rise. Three-wire parts are included in the design, providing for 120 volts between the neutral and the positive or negative leads, and arranged for a current of 520 amperes in the neutral continuously, on the basis of not exceeding rated current in the positive or negative leads of the generators. This is the equivalent of 25% unbalance.

**Frame.** The frame is split horizontally, thereby making it possible to remove the rotor without disturbing the lower half of the frame and the external lead connections which are located at the bottom of the frame.

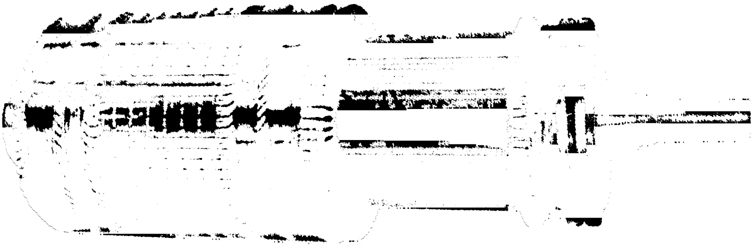


FIG. 15. Armature, 500-kw. generator, with shaft.

**Main poles.** The 4 main poles are constructed of electrical steel punchings which are securely bound together by through rivets. The poles are located symmetrically with respect to the magnet frame. The pole faces are provided with partially closed slots for housing the compensating windings. The clearance between the face of the main poles and the periphery of the armature core is approximately 0.25 in.

**Commutating poles.** The four commutating poles are constructed of electrical steel punchings. The portions next to the armature core are properly shaped to give the correct commutating field form. The clearance between the face of the commutating pole and the periphery of the armature core is approximately 0.69 in.

**Field windings.** The shunt field winding is made from No. 13 square copper wire which is double cotton covered. The coil is insulated from the pole body by means of treated fuller-board channels, and is wound directly on the pole with conductor under tension. Insulating washers are used adjacent to the pole tip. The individual layers of the winding are heavily coated with insulating varnish while being wound, thus insuring insulating treatment of all layers.

The series field winding consists of differential and cumulative windings. The differential winding is made of copper strap wound on edge from three 0.313 in. thick × 1.25 in. wide copper straps in parallel. The cumulative winding is made of copper strap wound on edge from three 0.25 in. thick × 1.25 in. wide copper straps in parallel. The copper straps are thoroughly treated with insulating varnish and are assembled around the shunt field, being supported by micarta hangers imbedded in the shunt winding. Spacing blocks in the form of wedges separate them from the shunt coils on all sides and spacers between turns allow free circulation of air around each conductor.

The commutating field windings are made of copper strap wound on edge from three .313 in. thick × 1.25 in. wide copper straps in parallel. The individual turns of the strap are spaced and securely clamped against the bore of the frame and brass bars set in the tip of the pole. The coil is insulated from the pole by heavy fullerboard shields completely surrounding the pole pieces. The coil is treated several times with an insulating varnish.

The compensating winding consists of copper strap, two 0.5 in. thick × 1.25 in. wide in parallel. The copper straps are insulated with fish paper and mica wrapper held securely in place by a layer of cotton tape. The insulation is then treated with a moisture and oil resisting insulating compound. The partially closed slots in the pole pieces are lined with heavy fish paper cells and copper straps are held firmly in place by means of wedges.

After all of the stationary windings have been assembled in position in the frame and necessary connections made between various coils, the complete stator, windings, etc. are given two dippings in a baking varnish and allowed to dry several hours in an oven at a temperature of approximately 100° C. after each treatment.

**Spider and core.** The spider is fabricated from steel bar and steel plate welded together. The design is very simple and rugged. Each of the spider arms are substantially welded to heavy end rings on both front and rear ends. The arms and end rings are machined, and the arms are then bored and held in position on the shaft by a press fit and a rectangular key.

The core is built up of special ring type punchings made of soft annealed steel, treated so that the iron losses will be a minimum. One of the spider arms carries a keyway to which the punchings are keyed throughout the entire length of the core. End plates cut from heavy hot rolled steel are used at both ends of the core. The punchings are assembled on the spider and then subjected to hydraulic pressure transmitted through the end plate and fingers which support the teeth. The end plate where the pressure is applied is secured by means of circumferential keys which are tack welded in place to prevent movement. Ventilating spaces are formed between the end plates and the end of the core as well as at suitable intervals along the width of the core by means of finger plate spacers. This arrangement permits cooling air to enter the inner portions of the core, furnishing means for dissipating the heat from the core.

**Armature windings.** The armature coils are formed of two copper straps connected in parallel, one conductor of 0.188 in. wide × 0.625 in. deep copper strap, the other of 0.156 in. wide × .625 in. deep copper strap. The individual conductors are insulated with one layer of mica tape, half overlapped. The straight portion of the assembled coil is then covered with a special prepared mica wrapper and fish paper, and the ends insulated with one layer of mica tape half overlapped. A layer of cotton tape is applied to the coil, and it is then dipped in a moisture and oil resisting compound and baked. The process is repeated until the proper amount of compound is deposited. The armature slots are lined with fish paper to protect the coil and insulation during assembly. Hard fiber wedges hold the coil in place, and the ends are held firmly against insulated supporting rings by steel banding wire. The banding wire is insulated from the coils by heavy fullerboard. Ventilating space between coil ends is maintained by spacers built into each coil.

The armature has a liberal number of insulated cross conductors to insure perfect electrical balance.

After the coils are assembled into the armature slots and banded in position, the complete armature is treated twice with a baking varnish.

**Commutator.** The commutator is made of hard drawn copper bars, insulated from each other by built-up mica and is insulated from the spider by molded mica vee rings. It is assembled on a cast spider, which is bored and held in position on the shaft by a press fit and a rectangular key. Separate front and rear vee rings, together with steel through bolts, clamp the assembled bars secured in place in such a manner as to prevent harmful distortion due to expansion and contraction of the bars under varying load conditions. The commutator mica is undercut to secure good brush contact. The brushes are staggered in pairs on arms to prevent uneven wearing due to electrolytic action of brushes carrying current.

**Three wire parts.** The generator armature is provided with two cast brass collector rings located at the front end of the machine between the commutator and the outboard bearing. The rings are connected to the armature windings through the ends of the properly located commutator bars. The lead to the outer ring is brought through the inner ring and is suitably insulated from same by means of a micarta tube. The neutral connection is obtained from an external balance coil connected to the collector rings through carbon graphite brushes supported by a suitable brush rigging.

**Brush rigging.** The brush rigging is of the heavy duty rocker ring and brushholder bracket type. Projecting steel arms welded to the frame support the rocker ring. This ring carries the brushholder brackets and is split horizontally to facilitate removal of the armature or top half of the frame. The ring can be shifted to secure the proper brush setting and then locked in position by means of the bolted locking device. The brushholders are of the double sliding box shunt type, die cast from bronze. A smooth finish is obtained by broaching the brush box surfaces of the die casting. This prevents sticking of the brushes and interference with commutation. Flexible braided copper shunts connect the brushes to the holders, preventing the passage of current through the springs, and thus protects them from damage. The spring tension is easily adjusted and is practically uniform throughout the life of the brush. The double brushholders are so constructed that individual adjustment for spring tension is possible.

The generators have 4 brushholder brackets, each bracket supporting 8 double brushholders. The carbon brushes used are the National Carbon Co. No. 259. These single brushes are 2-½ in. long, 1-¾ in. wide and ⅝ in. thick (64 required per set).

The slip ring brushes are supported by holders secured to studs, which are in turn bolted to micarta segments and rings fastened to the DC brushholders. The carbon brushes used are the National Carbon Co. No. 257. These brushes are 1-¾ in. long, 1-¾ in. wide and ¾ in. thick (8 required per set).

**Terminals.** The generator terminals are brought out in a vertical direction at the bottom. Three leads are provided, a positive, negative and an equalizer. The equalizer lead is connected between the cumulative series and differential series fields on the negative side of the armature. In each case the negative lead is in the center, with the positive and equalizer leads on either side to facilitate symmetrical layout of the cables connecting the generators to the auxiliary switchboard.

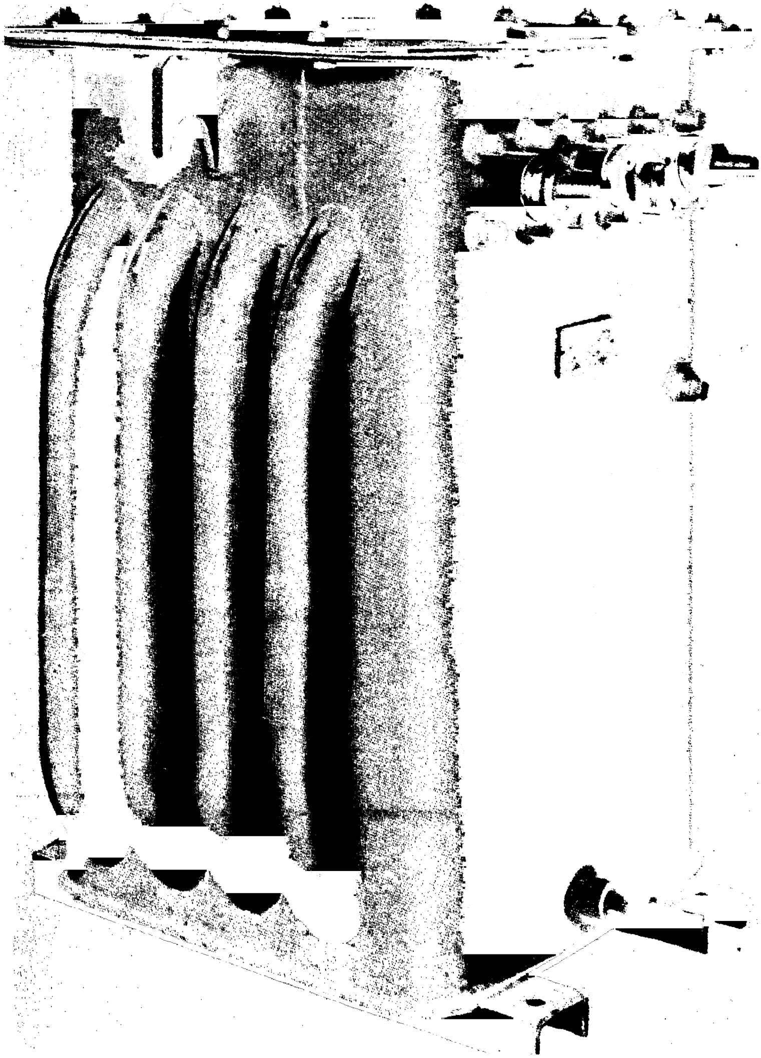


FIG. 16. General view of balance coil.

**Balance coil.** The balance coil (Figs. 16 and 17) used with the 500 kw. auxiliary generator provides for 120 volts between the neutral and the positive or negative leads, and are designed for 520 amperes in the neutral continuously. This is on the basis of not exceeding rated current in the positive or negative leads of the generator.

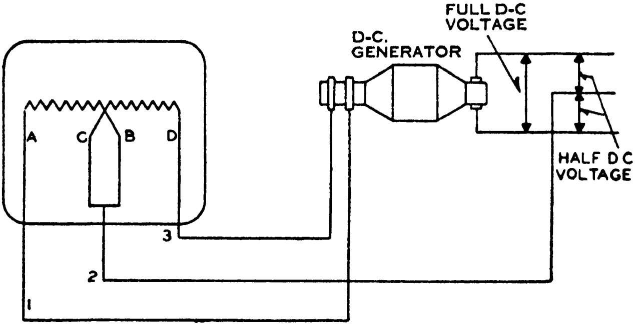


Fig. 17. Connection diagram of balance coil.

The coil is of the oil cooled, marine type mounted in a substantially welded sheet metal tank. Radiation tubes are provided on the side of the tank for dissipating heat. A sheet metal cover with gasket is bolted to the top of the tank, thereby preventing the loss of oil as well as preventing the entrance of dripping water, etc.

The coil is wound separately on a micarta tube and then assembled complete with an exact weight of L-shaped punchings, which are built up piece by piece, thus insuring uniformity of the iron loss and exciting current.

The assembled coils and iron are impregnated. The assembled units are first placed in an oven through which heated air is circulated. After the preliminary drying out process they are placed into a vacuum tank, all air and remaining moisture, which evaporates readily at low pressure, are removed. The impregnating compound, which consists of a mixture of resinous gums and which has been preheated is then drawn into the vacuum tank until it completely covers the coils. The air and moisture having been previously removed, the compound is drawn by capillary attraction into all the crevices of the winding, but to assure thorough coil penetration a pressure of 8 pounds per sq. in. is applied, forcing the compound into the winding. After a period of several hours the remainder of the compound is withdrawn and the coils removed from the tank and placed in a vertical position to cool.

## DC BALANCER SETS

As mentioned previously, balancer sets are dropping out of use. They are being replaced by balance or compensating coils. Mention is made of this subject because there are still a number of sets in use and doing good service.

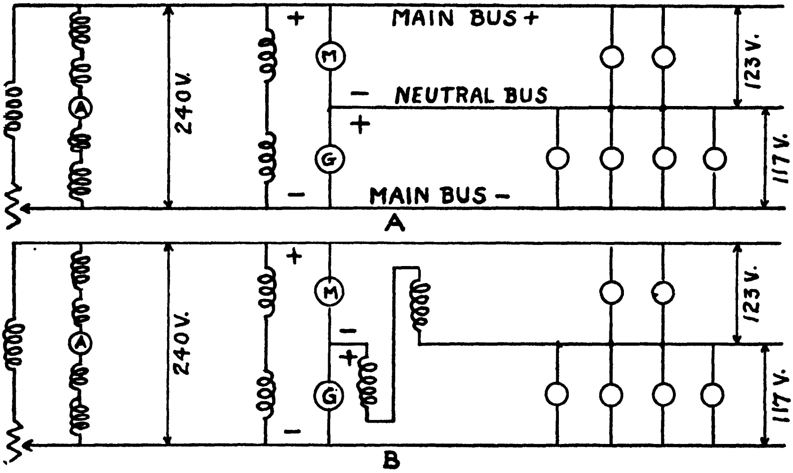


FIG. 18. *A*) Three-wire balancer set using shunt machine. *B*) Three-wire balancer set using compound-wound machine.

The balancer set comprises two DC machines, with either shunt or compound excitation, directly coupled to each other and connected in series across the outer conductors of a 3-wire system.

The shunt fields of the two machines are connected in series, and the neutral or third wire is taken off between the machines.

In compound sets the shunt fields are connected in series across the line. The series fields are placed in series in the neutral leg, which is connected to the mid point between the armatures.

In other compound excited balancer sets the series fields are cross connected, that is, the series field of one machine is connected in series with the armature of the other.

In Fig. 18A, as the load increases on the negative side the voltage decreases. At the same time the voltage increases on the positive side, thus causing the machine on the positive to motor. This in turn drives the other machine as a generator and supplies current to the negative side. This action tends to equalize the voltage and correct the unbalance.

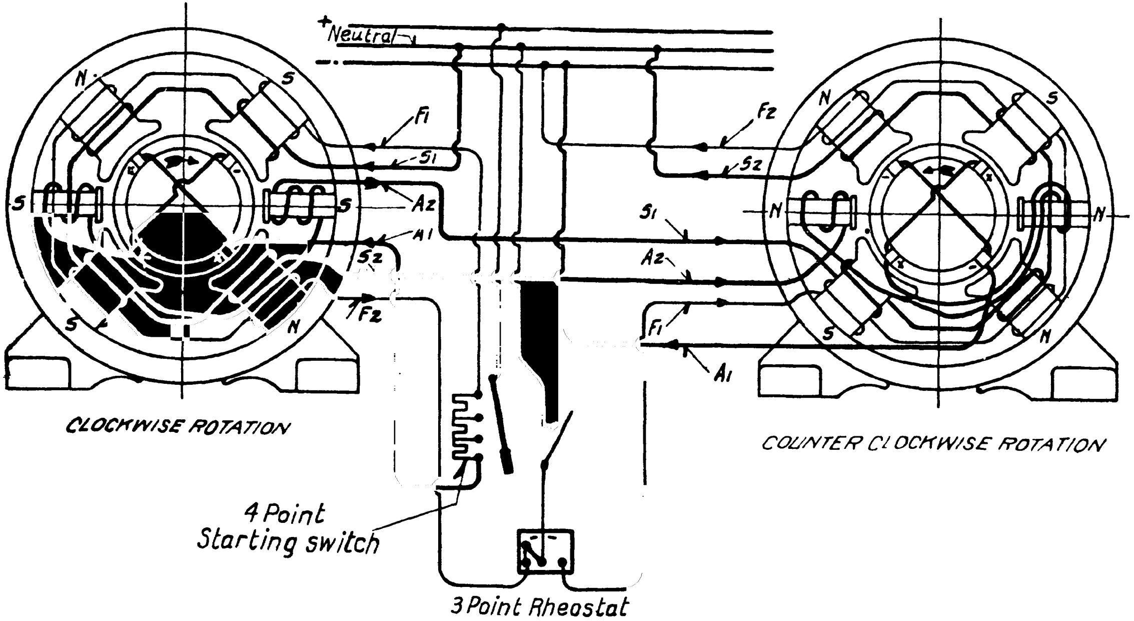


FIG. 19. Balancer set, 300 amps neutral, 120–240 v, schematic diagram of connections.

Fig. 18B shows a balancer set using a compound wound machine with its series fields in series. The operation is similar to that shown in Fig. 18A.

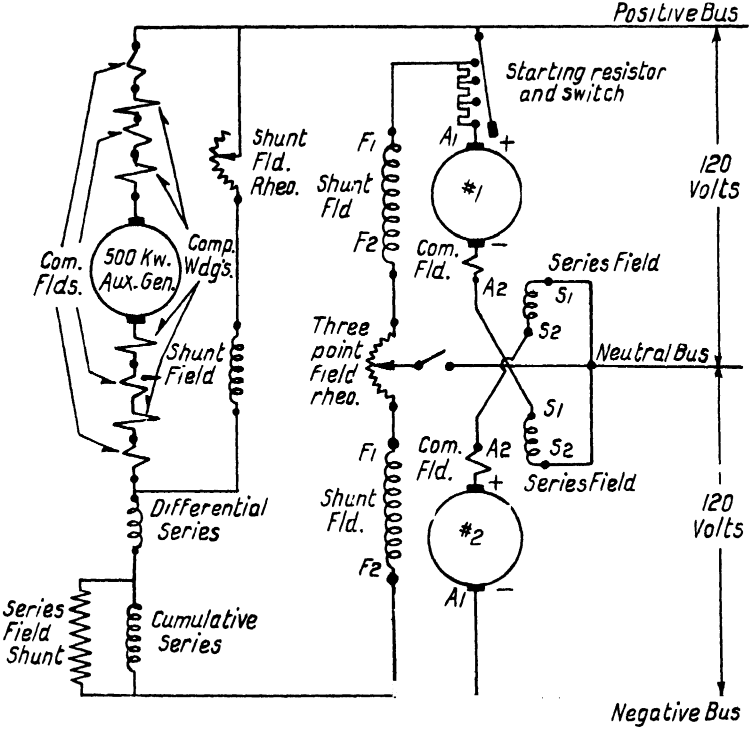


FIG. 20. Wiring connections of balancer set in Fig. 19.

The following is a description of the balancer set which may be used in conjunction with the 500-kw. generator in place of balancer coils described previously. The wiring is explained in Figs. 19 and 20.

These balancer sets are used for obtaining 120-volt 3-wire service from the 240-volt 2-wire bus connected to the 500-kw. auxiliary generators.

Each balancer set consists of two duplicate, compound wound, DC machines, coupled together and mounted on a common bedplate. The voltage rating of each unit is 120 volts, or one-half that of the voltage across the positive and negative terminal of the 500 kw. auxiliary generators. The current rating of each unit is 150 amps. Each balancer set is capable of handling 300 amps. unbalanced current in the neutral.

The balancer sets are started by means of a 3-step starting resistor similar to the method used for starting any DC motor. The armatures of both machines, together with the starting resistor, are connected in series across the 240-volt 2-wire bus. A 3-point field rheostat is used to adjust and balance the shunt field currents.

**Operation.** When the system load is balanced, each balancer unit operates as a motor, requiring only enough current to overcome the no-load losses. With unbalanced load on the system, the unit on the high-load side operates as a generator and the unit on the low-load side operates as a motor. There are losses in each unit and the voltage across the generator side will be less than that across the motor side. Consequently the current in the armatures of the two units will differ: the current in the motor side will be greater than the current in the generator side, inversely in proportion to the voltage on each unit.

By crossing the series field windings of each unit as illustrated in the diagrams, Figs. 19 and 20, less unbalance of voltage will occur. The generator's field will be strengthened, which will tend to raise its voltage. The motor's field will be weakened and it will tend to increase in speed, thus increasing the output voltage of the generator unit and more nearly equalizing the voltage on each side of the neutral.

## FIELD RHEOSTATS FOR 500-KILOWATT GENERATOR

The field rheostats are of the double face plate type and arranged for mounting on angle iron framework in the rear of the auxiliary switchboard. Each rheostat is operated from a hand-wheel located on the auxiliary switchboard through a system of bevel gears and shafting.

The front and rear face plates are made from ebony asbestos, and 154 resistance steps are provided. The resistors are designed to handle a maximum current of 10 amps.

Individual resistor units consist of German silver wire wound upon asbestos insulated wrought iron pipes. The assembly is then coated with a heat resisting cement. The leads are connected consecutively.

The rheostats have sufficient resistance to reduce the open circuit voltage of the generator to the residual value.

## ALTERNATING CURRENT GENERATORS

In marine practice these generators are polyphase synchronous wound for 3-phase 60-cycle current at 80% power factor. Each generator is supplied with a separate exciter which is either direct connected or separately driven.

Voltage regulators are used with each generator.

Alternating current generators are basically the same as direct current machines, that is, they consist of an armature and fields.

The fields are excited by direct current from an external source, and the relative motion between the armature and the field causes an alternating current to flow in the conductors of the armature.

There are two types of AC generators: with revolving armature and with revolving field. The former is seldom used.

One of the advantages of the rotating field type generator is that it has a stationary armature and requires no moving contacts (slip rings) to take off the current. This is of particular advantage in the higher voltages found in electric propulsion.

Slip rings are required, however, for field excitation but this is always moderate voltage and current. The number of poles of a rotating field is given by the formula:

$$N = \frac{120\,f}{\text{r.p.m.}}$$

where N = number of poles, f = frequency in cycles per second, and r.p.m. = revolutions per minute.

If the frequency and the number of poles are known, the r.p.m. may be found from

$$\text{r.p.m.} = \frac{120\,f}{N}$$

In steam installations where the prime mover is a direct drive turbine the speed is very high, usually 1800 or 3600 r.p.m. for 4 and 2-pole rotors (fields) when the frequency is 60 cycles. Geared turbines are also used with slower speed generators.

In Diesel installations, where the engine speeds are much lower, the number of poles is increased if it is desired to maintain the same frequency.

**Construction of AC generators.** The AC generator consists of two parts: the stator, which contains the armature windings, and the rotor, which contains the field windings.

The stator, or stationary part, consists of a heavy outer frame to which dovetailed ribs are attached, the core and the armature windings. The stator core is built up of annealed and enameled segments of thin sheet punchings, and is secured to the dovetailed ribs, which are attached to the stator frame. The inner side of the core is provided with slots for the reception of the armature coils. These coils are form-wound and thoroughly insulated with moisture-resisting insulation, and are held in the slots of the core by suitable wedges. The terminals of the coils are attached to heavily insulated end rings, which are securely attached to the end of the stator frame. The main current-carrying conductors are connected to the end rings, and, in marine installations, are usually brought out at the top of the stator frame. In the assembly of the stator core radial spaces at given intervals are provided for purposes of ventilation. The outer frame is covered with heavy metal lagging, which serves as a housing for directing the flow of air to the exhaust ducts.

The rotor, or revolving field, consists of a solid steel forging with grooves milled in its face for the reception of the field coils, the collector rings, and the ventilating fans. The solid-steel forging serves as a shaft and also as a core for the field portion of the magnetic circuit. The field coils, which are heavily insulated against moisture, are laid in the slots of the rotor and securely held in place by nonmagnetic metal wedges. The end turns of the field windings are held in place by end rings, which are shrunk in place. The two ends of the field winding are connected to the collector rings, which are mounted on the outer end of the shaft. The fans, which are connected to the rotor shaft, provide ventilation between the revolving and stationary parts of the generator and also through openings which are provided in the stator core. The brushes that convey the direct current to the collector rings and thence to the field windings are held in place by the brush rigging, which is mounted on the outer end of the bearing housing.

Small generators (auxiliary generators) are generally self-ventilating, but practically all modern electric-drive installations have surface type air coolers, which permit the continuous recirculation of the same air through the windings. This measure prevents the deposit of dust or other foreign material on the windings, and also prevents the entrance of oily or moisture-laden air which would tend to deteriorate the insulation or clog the ventilating air passages.

Temperature detectors are located at various points in the stator for determining the temperature of the windings. The readings, which can be taken at any desired time by using a plug situated on the control panel, are observed from a temperature meter also situated on the control panel. The temperature of the generator field windings is observed from a temperature indicator of the continuous-indicating type.

Electric heating coils are located inside the inner shields, one at each end of the generator, to prevent the accumulation of moisture on the windings during periods when the generator is idle. This is accomplished by keeping the temperature a few degrees above room temperature, thereby preventing the condensation that would occur if the temperature of the parts should fall below the temperature which corresponds to the dew point.

The generators are also provided with fire extinguishers, which are located inside the generator housing.

From an operating point of view, the engineer need pay little attention to the generator except to see that the bearings are supplied with good clean oil; to make periodic inspections of the collector rings, brush rigging, and brushes, to make sure that everything is tight and working smoothly; and to observe the temperatures of the windings during operation.

In installations provided with surface air coolers, the object is to regulate the water through the tubes of the cooler in sufficient quantity to cool the air, but not to permit the air to be reduced to a temperature lower than that corresponding to the dew point, which would permit condensation of moisture.

For further information and illustrations see section on Electric Propulsion.

# IV

# MOTORS

## CLASSIFICATION

Motors may be classified according to type, speed and mechanical features. The first classification is as follows:

**Direct current.** 1) Series. 2) Shunt. 3) Compound wound. 4) Stabilized shunt.

**Alternating current (single phase and polyphase).** 1) Synchronous. 2) Synchronous induction. 3) Induction, phase wound and squirrel cage. 4) Commutator.

According to speed, motors are classified as:

**Constant speed.** This covers cases where the speed is constant or varies but slightly.

**Adjustable speed.** This covers cases where the speed may be varied over a considerable range, but when once fixed remains at this value independent of the load changes.

**Varying speed.** This covers cases where the speed changes with the load, usually decreasing as the load increases.

**Multi-speed.** This covers cases where several distinct speeds may be obtained by changing the connections of the windings or by other means.

According to their mechanical features, motors are classified as:

1) Open. 2) Mechanically protected. 3) Semi-enclosed. 4) Totally enclosed. 5) Enclosed, externally ventilated. 6) Enclosed, self-ventilated. 7) Moisture-proof. 8) Splash and waterproof. 9) Submergible. 10) Acid proof. 11) Explosion proof.

**Limitations.** The principal limitations in the ratings of motors are: 1) Mechanical strength. 2) Heating. 3) Commutation. 4) Regulation. 5) Efficiency.

## DIRECT-CURRENT MOTORS

DC motors and DC generators are constructed in much the same manner. In fact, they are practically alike in every respect except application.

The generator is supplied with mechanical power and delivers electrical power or work, while the motor is supplied with electrical power and delivers mechanical power or work.

DC marine motors have the following performances in the 4 classes indicated:

| Type | Speed | Torque |
|---|---|---|
| Shunt | Constant | Moderate |
| Series | Varies with load | High starting |
| Compound | Decreases rapidly with load | Moderate |
| Stabilized Shunt | Drops slightly with increased load | Moderate |

The shunt motor's field is located in parallel with the armature, and speed control is accomplished by varying the resistance of the field circuit by the introduction of a rheostat.

Shunt motors are used where constant speed is the prime requirement. They will be found driving pumps, ventilation blowers, compressors, forced draft fans, steering gear pump motors, etc.

The series motor has its field in series with its armature. This motor is used where high starting torque and high torque at low speeds is of first importance. It will be found in use where hoisting is required, such as with cargo winches, cargo cranes, lifeboat winches, and windlass and capstan. Speed control is usually accomplished by varying the voltage applied to the motor by the introduction of resistance in the armature circuit. This is done by contactors operated by a master switch. These contactors cut in and out resistor units as required. In some cases where performance requirements are quite simple and the horsepower of the motor is not high, a drum controller (manually operated) is used. In this type of controller the contacts are large enough to carry the main line or armature current, and are connected directly to the resistor units.

Compound motors have both shunt and series connected fields, and, according to the proportion of the series field to the shunt field, perform more or less like series motors. This arrangement allows a motor design having the desirable characteristics of both shunt and series motors.

The compound motor will be found driving shaft-turning gears, air compressors, sewage pumps, warping capstans, boat winches, cargo winches, etc.

The stabilized shunt motor is a shunt wound motor having a light series winding added to prevent a rise in speed or to obtain a slight reduction in speed when the load is increased. This type of motor is used for ventilation fans, blowers, cold air diffusing fans, and compressors.

Speed control of stabilized shunt motors is accomplished by the same methods that are used for shunt motors.

It will be noted that in the foregoing discussion the same application has been given for more than one type of motor. For example, cargo winches were listed as having both series and compound motors. In the case of a cargo winch the controller is sometimes arranged to operate the motor as a series motor at one speed and a compound at another. However, the hoisting motor is predominately series.

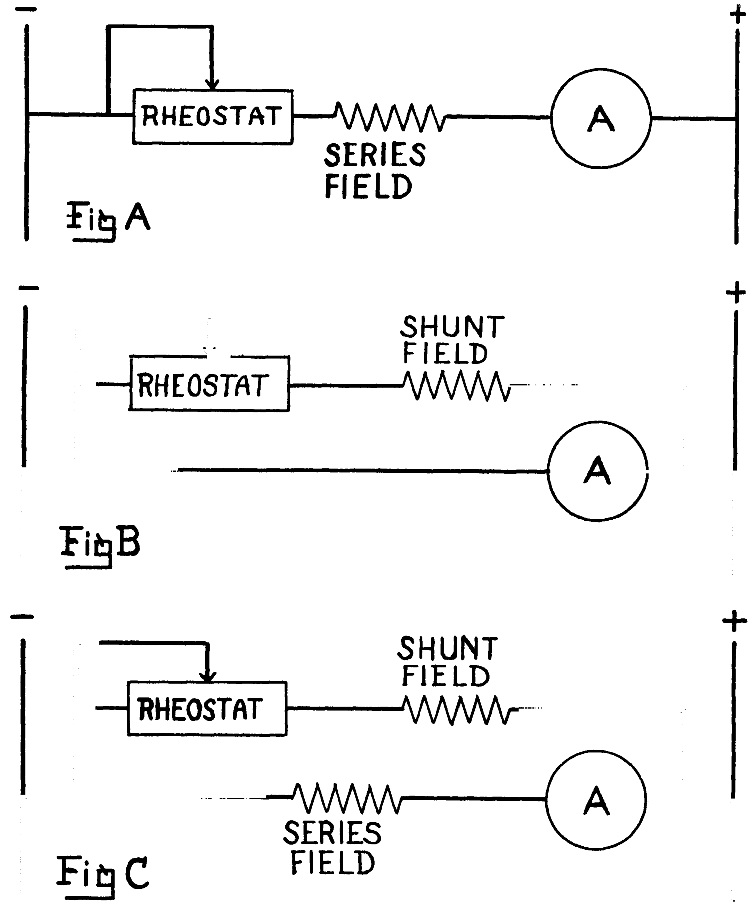


FIG. 21. Simple diagrams of 3 most common motors. *A*) Series. *B*) Shunt *C*) Compound.

Marine DC motor frames are commonly divided into two main classes: above deck (waterproof) and below deck (usually drip proof).

On oil tankers or other ships that may have motors in hazardous locations (due to inflammable gases) explosion-proof construction is used to avoid the possibility of internal explosions.

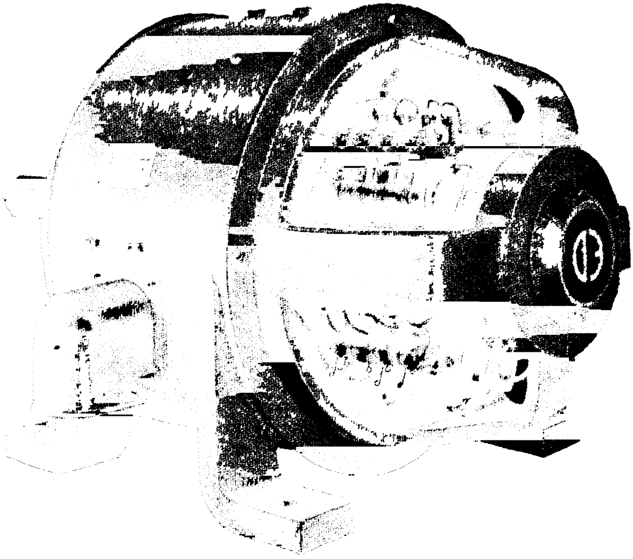


FIG. 22. Welded frame, semi-enclosed type DC machine. Brush rigging can be plainly seen

Shipboard motors are with but few exceptions installed with their shafts fore and aft.

A simple diagram of the three most common motors met with on shipboard is shown in Fig. 21. No details are shown in this diagram.

The machine shown in Fig. 22 might be a series, shunt, or compound motor or generator. The kind could only be determined by knowledge of its field windings and connections.

In Fig. 23 is shown a DC compound wound waterproof type motor opened up to show the relation of the various units. Note how the series and shunt fields are wound on the same pole.

The following illustrations (Fig. 24) of motor parts with short descriptions will familiarize the beginner with the various units that make up a DC motor or generator.

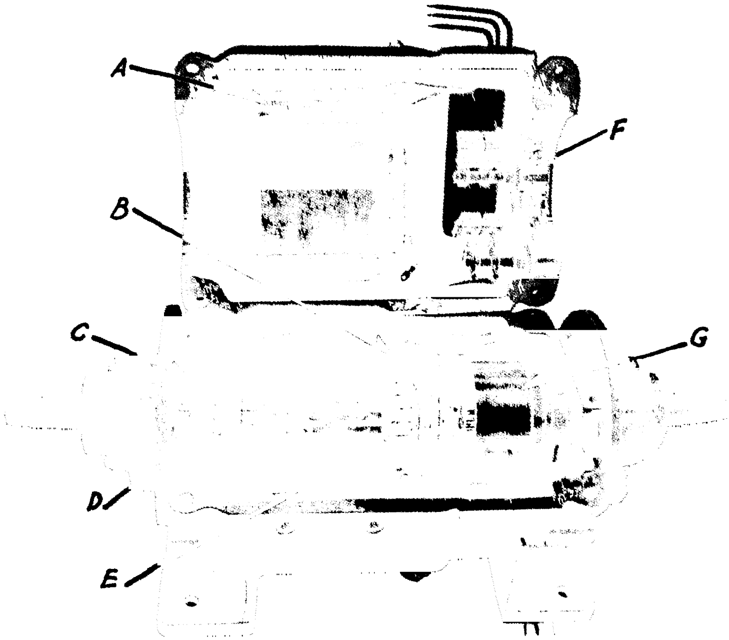


FIG. 23. Waterproof type compound DC motor used for deck machinery. *A*) Field coils. *B*) Armature coils, held in slots by banding wire. *C*) Oil ring slot inside of motor. *D*) Bearing housing bolted to end of frame. *E*) Field coils, held in place by heavy leaf springs. *F*) Two brush arms located in upper half of frame. *G*) Commutator.

For further detailed information on DC motors see Maintenance Section.

For a complete description of DC motor and generator construction see Generator Section.

FIG. 24 **(opposite page).** Units of a series motor with compensating or interpole coils. *A*) Armature barrel assembled on shaft. *B*) Armature with bearing cartridges *C*) Brush rigging. *D*) Main pole. *E*) Main field coil. *F*) Interpole coil. *G*) Interpole.

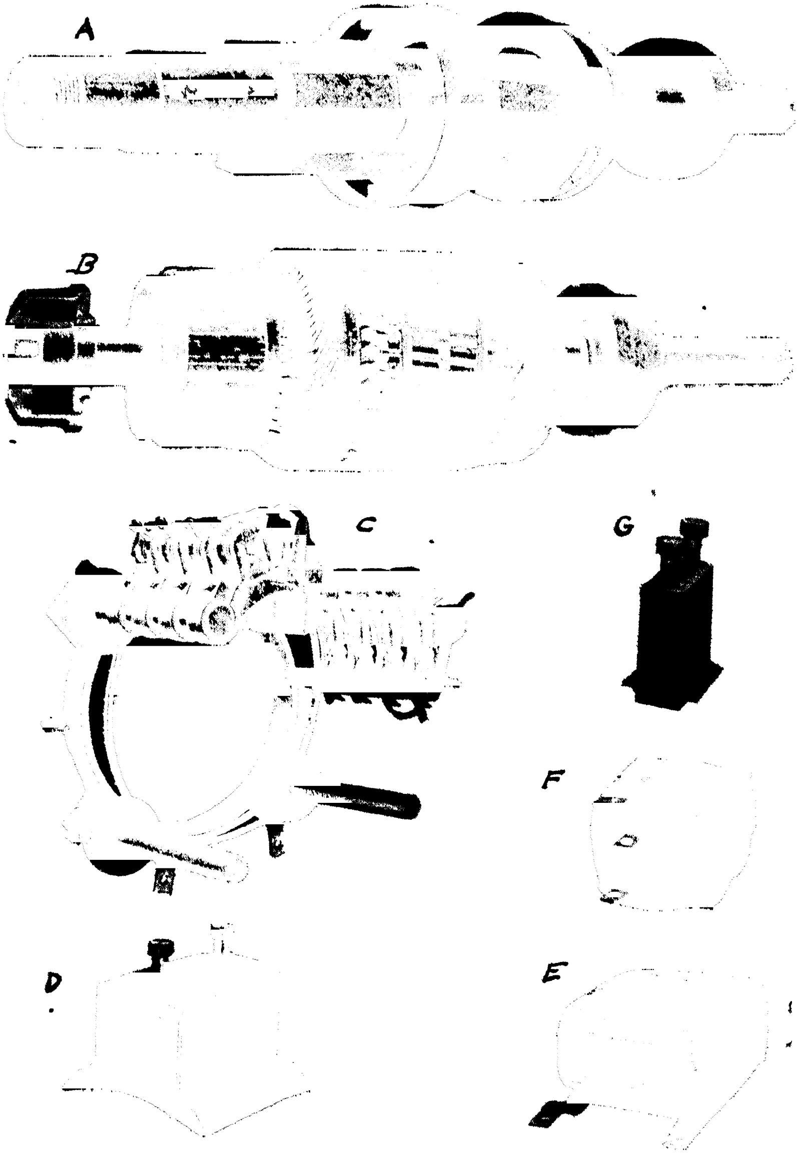


FIG. 24. (See opposite page.)

## ALTERNATING-CURRENT MOTORS

In marine practice where alternating current is used, 3-phase is almost exclusively the rule, although there may be single-phase motors found driving small electric appliances.

AC marine motors are manufactured in the following classes with performance as indicated.

| Type | Speed | Torque |
|---|---|---|
| Squirrel Cage Induction (Low Slip) | Nearly constant | Low |
| Squirrel Cage (High Slip) | Decreases rapidly with load | Moderate |
| Wound rotor | Constant—variable | Fair |
| Synchronous | Constant | Moderate |

A frequency of 60 cycles is now almost universally used for general power distribution.

Polyphase (2 or 3 phase) motors operate on the principle of the revolving field, somewhat as follows:

Since, in a 3-phase circuit, each phase becomes positive in succession and also negative in succession as in Fig. 25, the coils energized by the 3 phases would have their polarities successively N.N.N., S.S.S., etc.

If these coils were arranged about the circular frame of a motor, the magnetic North flux produced by the coils would move successively from coil to coil around the frame, and correspondingly the South flux would track around with the North (being the other pole of the magnetic field). This results in a revolving magnetic field.

If a squirrel cage rotor (easily identified by its copper bars making a cage-like rotor) is placed in this field the bars of the rotor will be cut by the rotating flux. Since all the bars are connected together current will circulate through the bars, and a separate magnetic flux will be set

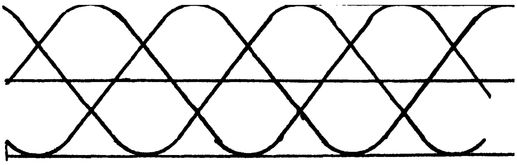


FIG. 25. Sine curves of 3-phase alternating current.

up by each bar. This flux links with the flux of the rotating field and a torque occurs.

An induction motor depends on slip for its torque or turning effort, because the difference in speed (slip) between the rotating field and the rotor is the speed at which the revolving field cuts the copper bars of the squirrel cage rotor or the winding of the wound rotor.

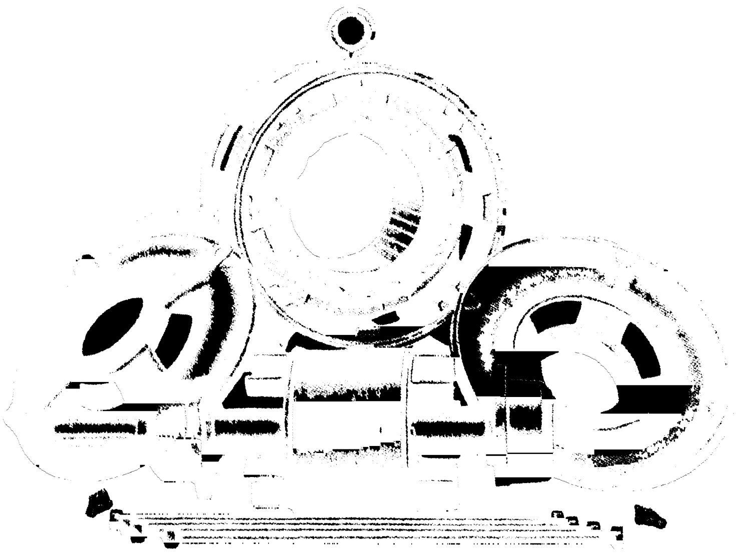


FIG 26. Disassembled squirrel cage induction motor, showing all parts.

Although polyphase AC motors depend upon this single principle, they can be further divided into two main groups: namely the non-synchronous and the synchronous. Those which revolve out of step with the revolving field or have slip are said to be non-synchronous, and those which are in step with the revolving magnetic field are said to be synchronous.

Of the non-synchronous, the squirrel cage is the most common and is used where constant speed is required, such as on blowers, fans, steering gear pumps, etc. (See Figs. 26, 27.) These motors are supplied with different torque characteristics to meet different duties, including compressors and reciprocating pumps, engine turning motors, etc. The squirrel cage motor reaches its full load torque at from 85–95% of synchronous speed, depending on the particular design. Beyond this the rotor current and torque decrease to zero at synchronous speed.

Where it is desirable to provide adjustable, varying speed motors having high starting torque and very low starting current, the squirrel cage rotor is replaced with a wound rotor. This rotor carries a winding which is brought out to slip rings, and through brushes sliding on these slip rings resistance is inserted in the rotor circuit. The effect of this resistance on the induced rotor current is to decrease its lag and bring it into phase with the induced e.m.f. This produces a decrease in speed.

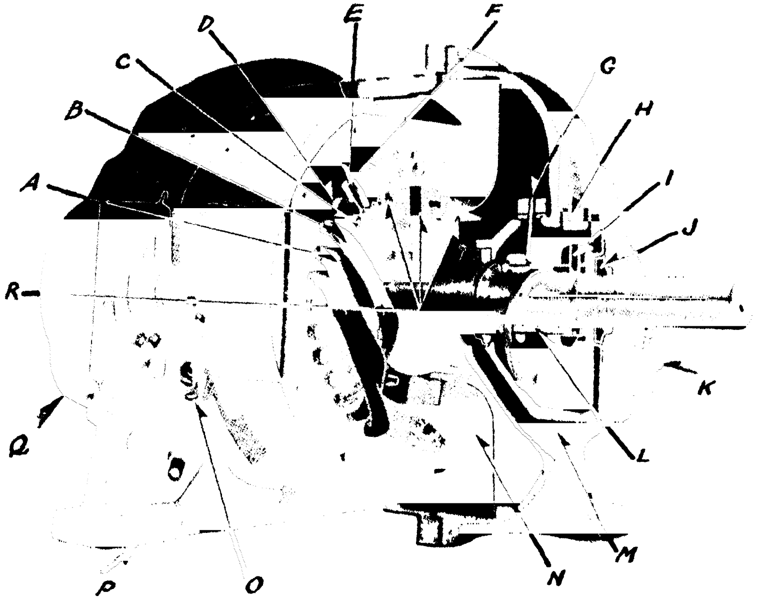


FIG. 27. Squirrel cage induction motor, showing winding (Westinghouse). *A*) Taped end turns. *B*) Formed coils of insulated wire. *C*) Wedges fit around wires. *D*) Cuff for coil insulation. *E*) Combination slot cell with cuff on each end. *F*) Partially closed slots. *G*) Heavy gasketed cover with keeper. *H*) Pipe plug over bearing locking screw. *I*) Bearing locking screw. *J*) Felt washer. *K*) Overflow and filler plug. *L*) Sealed sleeve bearing. *M*) Air by-pass to prevent suction of oil vapor. *N*) Varnish coat. *O*) Reconnectable here for 220 or 440 v. *P*) Feet, cast integral with frame. *Q*) Conduit box. *R*) Rotor bars, end rings and blowers.

The slip-ring or wound rotor induction motor (Figs 28–30) is used where heavy starting torque and low starting current is required, and where varying speed control is a necessity Its application on shipboard is to be found in windlasses, towing and warping winches, steering gear, capstans, pumps, boat hoists, etc

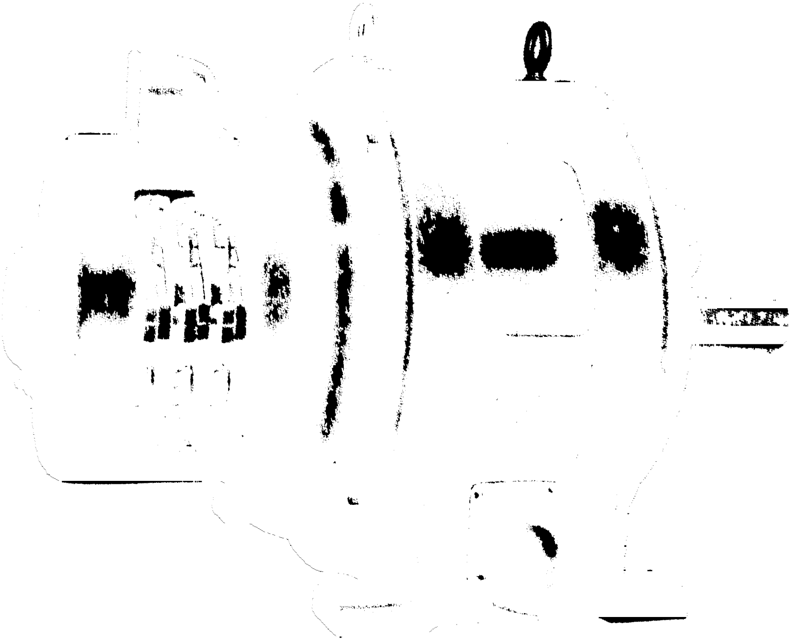


FIG 28 Slip-ring or wound rotor motor (Electro-Dynamic)

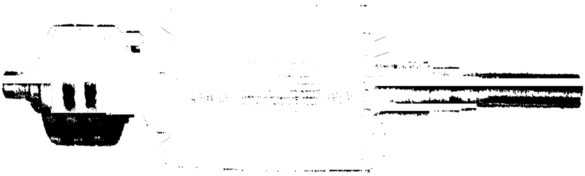


FIG. 29 Rotor of slip-ring motor in Fig 28.

**Slip.** The slip (difference between the speed of the revolving magnetic field and the rotor speed) varies from 4% to 18% (hoist motors), and is found by the formula used to determine alternator r.p.m.—

$$\text{r.p.m.} = \frac{120\,f}{P} \times \%\ \text{slip} \qquad \begin{array}{l} f = \text{frequency} \\ P = \text{no. poles} \end{array}$$

**Example.** Find the speed of a squirrel cage induction motor having an 8-pole winding operating at 60 cycles with 4% slip.

$$\begin{aligned} 4\%\ \text{slip} &= 100\% - 4\% = 96\%\ \text{synchronous speed} \\ \text{r.p.m.} &= \frac{120 \times 60}{8} \times 96\%\ \text{synchronous speed} \\ &= \frac{7200}{8} \times .96 \\ &= 900 \times .96 \\ &= 864\ \text{r.p.m.} \end{aligned}$$

$$\begin{aligned} \text{The \% synchronous speed} &= \frac{\text{r.p.m.} \times P}{120\,f} \\ &= \frac{864 \times 8}{120 \times 60} = \frac{6912}{7200} = .96 \text{ or } 96\% \end{aligned}$$

The following are the synchronous r.p.m. for different pole motors at 60-cycle frequency.

| No. Poles | r.p.m. |
|---|---|
| 2 | 3600 |
| 4 | 1800 |
| 6 | 1200 |
| 8 | 900 |

The current taken by a 3-phase induction motor is

$$I = \frac{\text{watts}}{\sqrt{3} \times E \times \text{eff.} \times \text{pf}}$$

where total watts = 746 × HP

$$\begin{aligned} E &= \text{line voltage} \\ &\left.\begin{array}{l} \text{eff.} = \text{efficiency-ranges from 78 to 91\%} \\ \text{pf} = \text{power factor from .78 to .92} \end{array}\right\} \text{depending on frequency and size} \\ \sqrt{3} &= 1.73 \end{aligned}$$

A motor of 75 HP operating at 440 v. with an eff. of 88% and a pf of .92—

$$\begin{aligned} I &= \frac{746 \times 75}{1.73 \times 440 \times .88 \times .92} \\ &= \frac{55950}{616.27} \\ &= 90.8\ \text{amp.} \end{aligned}$$

**Synchronous motor.** As the name indicates, this type of motor runs at a speed in synchronism with the revolving field. This speed can be calculated by the same formula used above

The motor consists of an armature (stator) wound around the frame exactly as in the case of an induction motor. The rotor (Fig. 31) however is composed of an equal number of poles, the field coils of which are connected in series and brought out to 2 slip rings. Direct current from an "exciter" is connected to these slip rings. The function of this direct current is to energize the field coils, thereby producing North and South poles.

Embedded in the surface of the poles are the copper bars of a squirrel cage winding. By the use of this winding the synchronous motor is started as an induction motor; and when it reaches a speed of about 96%

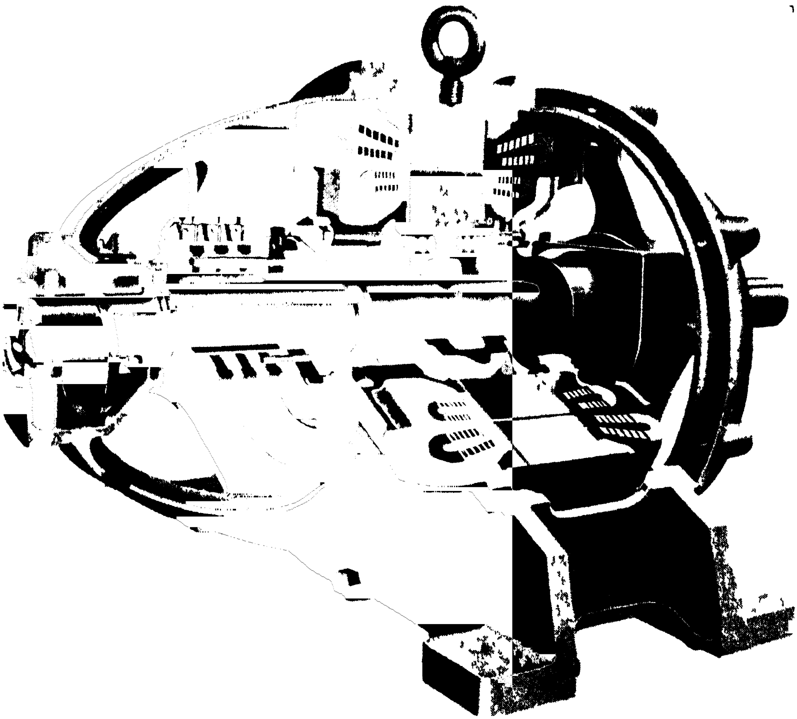


FIG. 30 Three-phase wound rotor induction motor (Westinghouse).

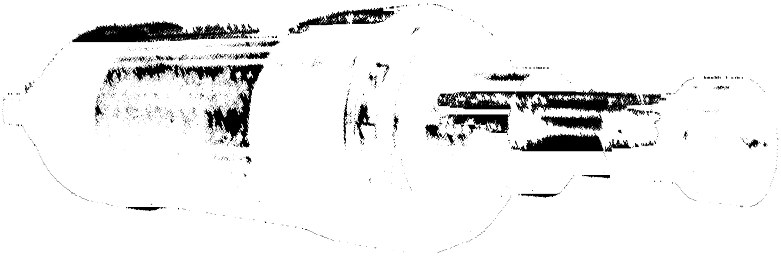


FIG. 31 Synchronous motor rotor, completely assembled.

synchronous speed the direct current supply is turned on In practice this is done as slowly as possible, because sudden application of the field current would jar the rotor as it is pulled into synchronous speed by the rotating field.

The field coils may be energized from any direct current source and are often supplied from small direct current generators connected directly to the shaft of the synchronous motor.

The use of the synchronous motor is somewhat limited in marine work and will be found in some electrical propulsion ships as the main propulsion motors. The speed of a synchronous motor—

$$\text{r.p.m.} = \frac{120\,f}{P} \qquad \text{where } f = \text{frequency in cycles per second and } P = \text{no. of poles}$$

For a 4-pole machine at 60 cycles this would be—

$$\text{r.p.m.} = \frac{120 \times 60}{4} = \frac{7200}{4} = 1800 \text{ revolutions per min.}$$

And again at 25 cycles, having 8 poles the speed will equal—

$$\text{r.p.m.} = \frac{120 \times 25}{8} = \frac{3000}{8} = 375 \text{ revolutions per min.}$$

This shows clearly that the two factors which control the speed of synchronous motors are the number of poles and the frequency in cycles per second. The current in the line taken by a 3-phase synchronous motor is

$$I = \frac{\text{watts}}{\sqrt{3}\,E \times \text{eff.} \times \text{pf}}$$

where $\sqrt{3} = 1.73$
$E$ = line voltage
eff. = efficiency
pf = power factor
746 = no. of watts per HP

For a 150-HP motor operating at 440 volts, an eff. of 90 per cent and a pf of unity, the current would be—

$$\begin{aligned} I &= \frac{746 \times 150}{1.73 \times 440 \times .90 \times 1} \\ &= \frac{111900}{685.08} \\ &= 163.3 \text{ amp.} \end{aligned}$$

The efficiencies vary both with the size of the motor and with the frequency: the lower the frequency, the higher the efficiency.

For single-phase work three classes of AC motors are used: the repulsion-induction motor, the single-phase synchronous motor, and the single-phase series motor.

The **Repulsion-induction** motor and the **series** motor are both commutator type machines, and look like an ordinary DC series motor.

These motors differ in actual design mainly in the fact that the AC machine has laminated pole pieces to reduce eddy currents.

The repulsion-induction motor starts as a repulsion motor and runs as a squirrel cage induction motor, because at normal speed the armature is short-circuited, that is the armature brushes are connected together.

This method gives high starting torque, about 300% full load torque, and is known as the repulsion method of starting. After the motor comes up to speed a centrifugal switch completely short circuits the commutator, and the motor then runs as a squirrel cage induction motor.

The series motor, when used for AC work, is connected both internally and externally as when used with direct current. Therefore it can be used for both services. The field core should be laminated for AC service. The torque and speed characteristics of AC operation are very similar to those of DC operation.

This means that the series motor on AC service is used where high starting torque is required.

The single phase synchronous motor is the same machine as a single phase alternator. However, it is usually not self-starting and must be brought up to speed by external means, which is usually accomplished by a separate motor. This motor runs at synchronous speed, which may be calculated the same as for the polyphase alternator.

For further description and illustrations of AC motors see Electric Propulsion Section.

# V

# MOTOR STARTING AND CONTROL EQUIPMENT

Starting and control equipment may be grouped into two main classes, namely, manually and magnetically operated. The former is operated directly by hand and the latter by an externally operated control circuit.

**Manual starters and controllers (heavy type).** Manual starters and controllers may again be divided into two main types: the face plate and the drum.

The face plate type consists of a panel or plate of insulation, mounted on which is a pivoted arm having a contact. (Figs. 32, 33.) This arm is arranged to move through an arc of about 60°, and the contact is allowed to slide over a set of studs arranged along the arc. These studs are connected at the back of the panel to a resistor unit, forming a number of taps. This method allows the operator to start the motor at a reduced voltage, thereby limiting the starting current to predetermined values. As the motor speed picks up, resistance is cut out, until the motor reaches full speed.

At this point the arm, which is iron, comes in contact with an electromagnet (the coil of which is connected in series with the shunt field of the motor). This magnet holds the arm in place while the motor is running. Any failure of voltage will de-energize the coil and the lever will be returned to the off position (by a spring).

The magnet is referred to as the "no voltage release magnet."

**The compound starter** is similar in construction and design to the face plate starter, except that it is provided with an arrangement of two arms which move together and permit the starting of the motor as previously mentioned, and speed regulation as explained below.

When the motor is up to speed the starting arm is held by the "no voltage release magnet" as in the panel type starter, and the control arm is free to be moved back. (See Fig. 34.)

As the speed control arm moves back it cuts in resistance in the shunt field circuit of the motor and the speed is increased.

The above starters are used with shunt and compound wound motors.

In the case of manual starters of the panel form, the starting arms are arranged so that the motor will be stopped if the arm is left on a starting point, except the full speed contact.

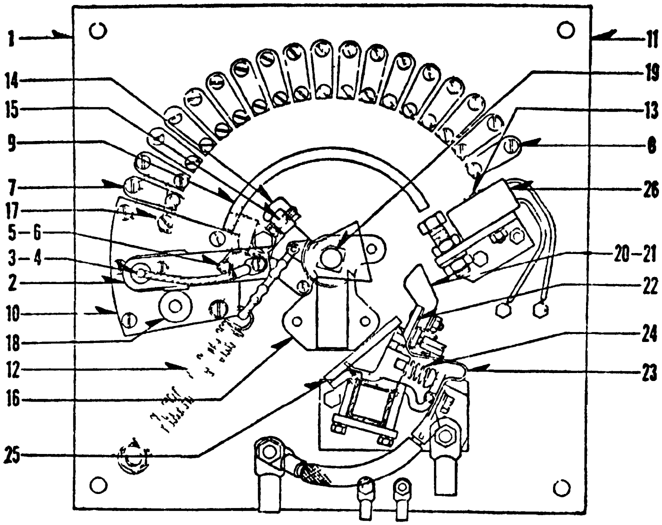


FIG 32 Typical 25-HP, DC face plate type manual starter and controller

| | *List of Parts* | *No Per Rheostat* |
|---|---|---|
| 1 | Face Plate Complete | 1 |
| 2 | Contact Arm Complete with Contact | 1 |
| 3 | Contact with Shunt--Main | 1 |
| 4 | Contact Spring—Main | 1 |
| 5 | Contact without Shunt—Auxiliary | 1 |
| 6 | Contact Spring—Auxiliary | 1 |
| 7 | Stationary Contact | 18 |
| 8 | Stationary Contact Stud | 18 |
| 9 | Stationary Contact Segment | 1 |
| 10 | Rider | 1 |
| 11 | Base | 1 |
| 12 | Return Spring | 1 |
| 13 | Magnet Core | 1 |
| 14 | Contact | 1 |
| 15 | Contact Screw | 2 |
| 16 | Bearing Bracket | 1 |
| 17 | Blowout Coil | 1 |
| 18 | Rubber Stop | 1 |
| 19 | Shaft Assembly | 1 |
| 20 | Type A Contact Finger | 2 |
| 21 | Finger Tip | 2 |
| 22 | Finger Base | 2 |
| 23 | Finger Shunt | 40 |
| 24 | Finger Spring | 2 |
| 25 | Finger Arc Barrier | 2 |
| 26 | Magnet Coil | 1 |

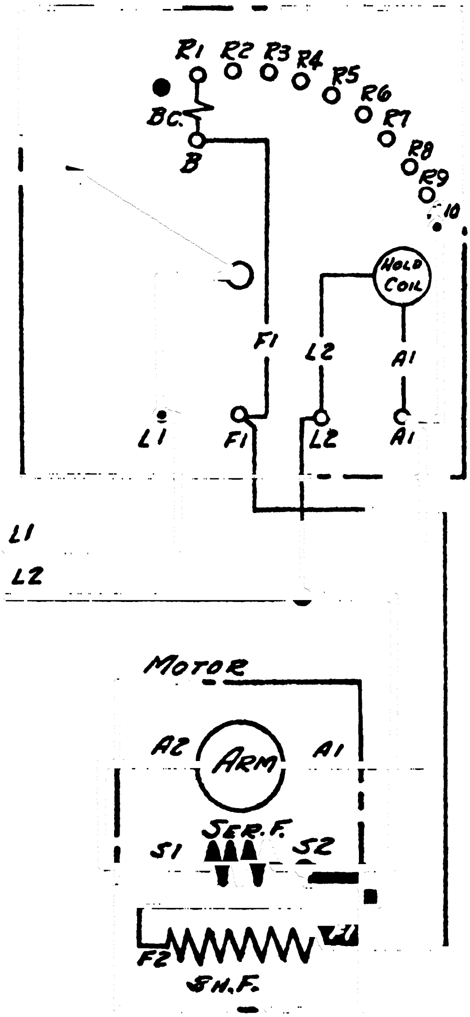
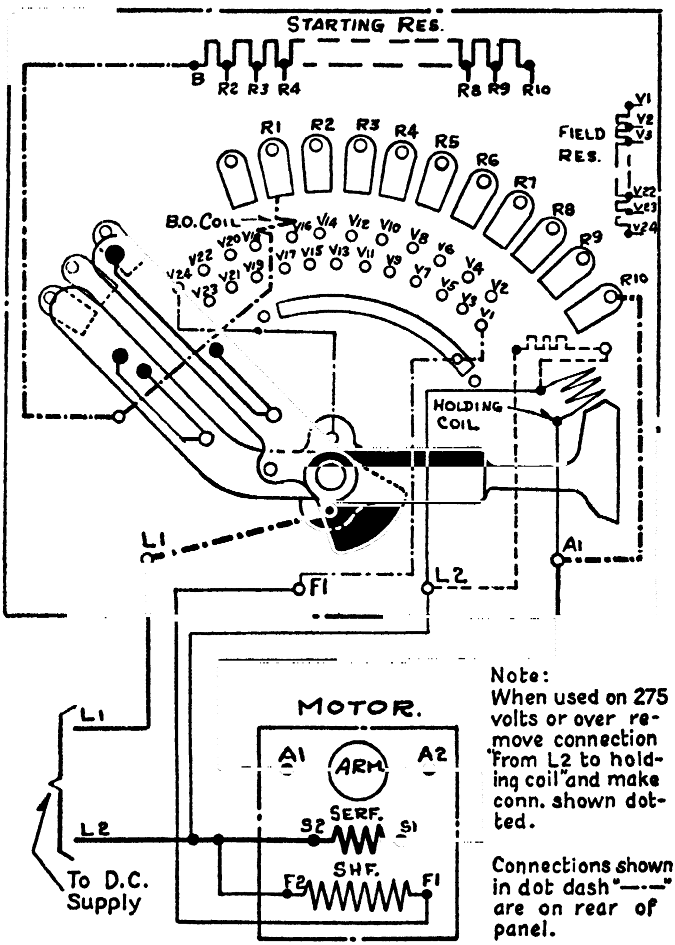


FIG. 33. Typical wiring diagram for face plate type, starting duty only. Diagram is for compound wound motors. For shunt wound motors the series field coil is omitted.



Note:
When used on 275 volts or over remove connection "from L2 to holding coil" and make conn. shown dotted.

Connections shown in dot dash "—·—" are on rear of panel.

FIG. 34. Typical wiring diagram. Starting and speed regulating duty by field control only. Diagram is for compound wound motors. For shunt wound motors the series field coil is omitted.

The same result should be accomplished in the case of the drum form of manual control unless a starting resistor is incorporated, with the control having sufficient capacity to carry rated motor current for 15 min. (This does not apply to the regulating drum form controller such as is used for deck winches, etc., in which the resistor is proportioned for the duty cycle.) Manual starting apparatus, except for motors which can be safely restarted across the line, should be designed to prevent automatically the application of full voltage to a motor, the speed of which has been materially reduced by a voltage failure.

DC face plate speed regulators are similar in construction to panel type controllers, except that the arm will stay in any position it is placed. It is also designed to reduce the speed below normal as well as to increase it. Figs. 35, 36 are starters for special duty.

**Panel type AC starters, controllers and speed regulators.** Face plate starters of the DC type, with slight modifications, may be used for single-phase series or repulsion motors. The design details are modified for AC work. (See Fig. 37.)

For polyphase motors the panel type starters and speed regulators are used. For wound rotor induction motors they are arranged to vary the resistance in each phase at the same time. For 3-phase machines they have 3 arms spaced 120° apart, riding over 3 sets of resistor contacts.

The panel type equipment (face plate) will be found on older ships and occasionally on modern vessels.

**Drum controllers.** These consist of a shaft operated by a lever or crank handle on which are mounted a number of insulated copper cams.

Parallel to this rotor is a row of insulated contact fingers, held by springs. As the shaft rotates the cams come into contact with the fingers. Certain cams are connected together by straps. No wiring is attached to the cams. They merely act as contacts between 2 or more fingers.

Drum controllers are used to cut in and out resistance for the manual operation of motors or as master switches for the control of magnetic type motor control panels. (See Fig. 39C.)

**Magnetic time starters and controllers.** (Refer to Figs. 38, 39.) The contacts which carry the motor current are operated by electromagnets which are designed to automatically accelerate the motor to a predetermined speed. In order to start the automatic acceleration or stop the motor, two types of manually operated master switches are in general use. One consists of a "start-stop" push button and the other a small type drum controller. These master switches conduct only the small current required to operate the electromagnets.

These magnetic controllers are frequently made fully automatic by

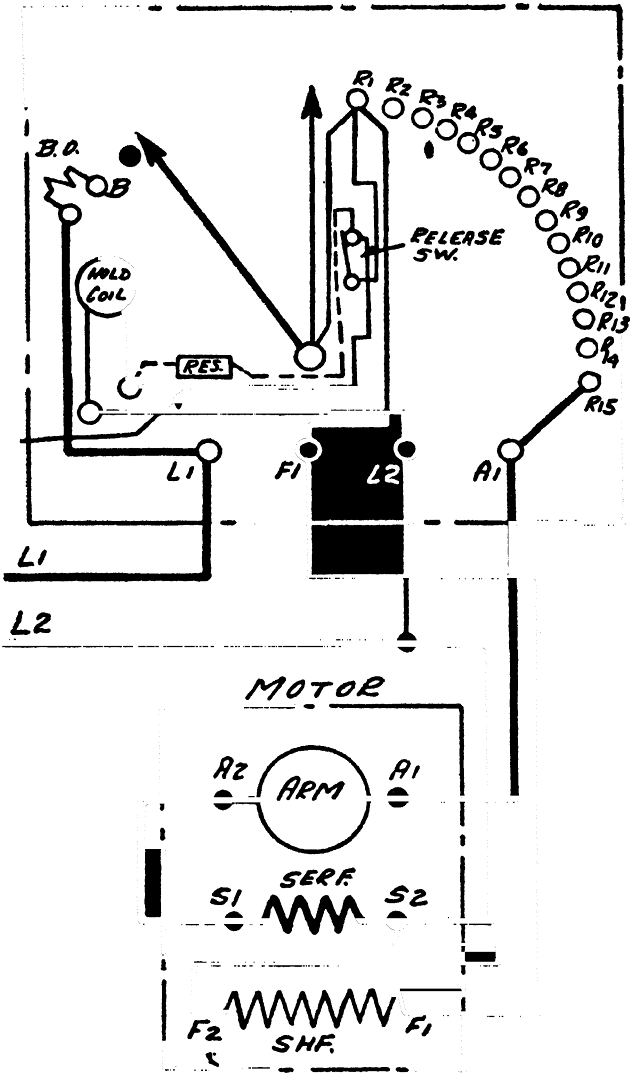


FIG. 35. Special duty face plate type. Typical wiring diagram for regulating duty. 50% speed reduction by armature control. This diagram also is for compound wound motors. For shunt wound motors the series field coil is omitted.

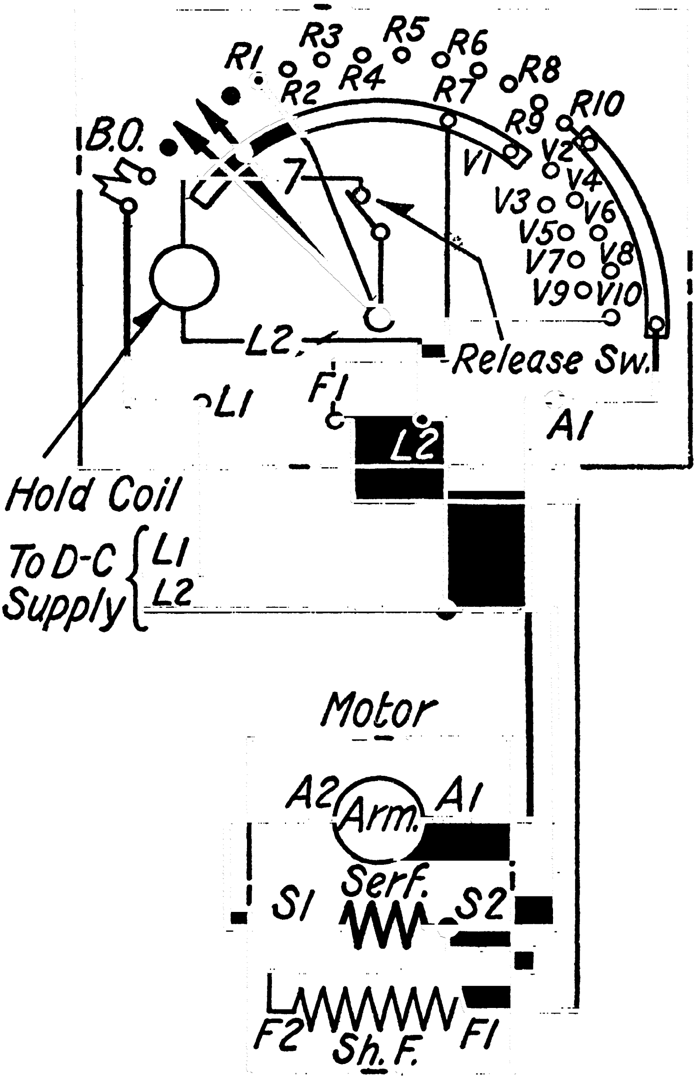


FIG. 36. Another special duty face plate type. Typical wiring diagram for regulating duty. 50% speed reduction by armature control and 25% increase by field control. Diagram for compound wound motors. Omit series field coil for shunt wound.

the use of temperature, pressure, humidity, float or illumination operated devices which start and stop the motor within predetermined limits. In this case a "Hand-Automatic" selector switch is installed, which allows for automatic or manual control as desired.

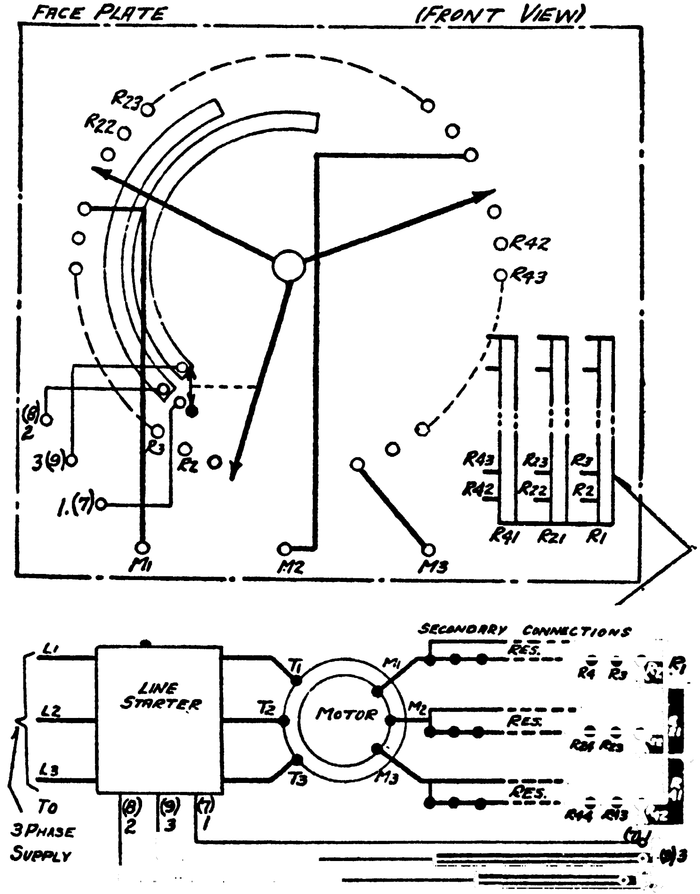


FIG. 37. Typical wiring diagram for 1/4–25 HP 3-phase AC face plate controller. *Note:* Connect marked leads on the resistor to similarly marked points of the face plate, except R1–R21–R31, which are common on the resistor. At bottom of figure is the elementary controller diagram.

When magnetic control is used for adjustable speed motors which cannot be safely started under weak field conditions, a magnetic relay is provided to short circuit the field rheostat during starting, until full voltage is across the motor armature

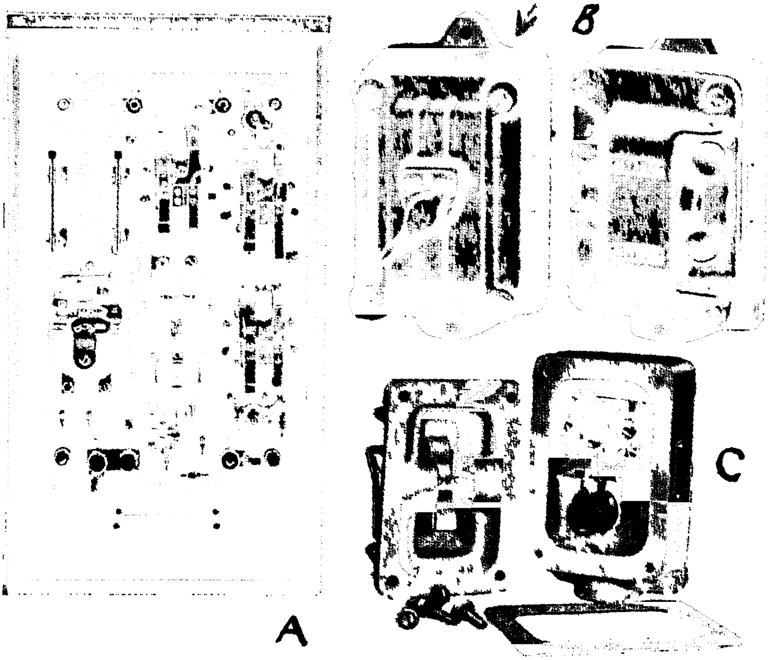


FIG 38 Magnetic time starter with typical push-button control and selector units A) Time starter for 30 HP Watertight 2-button station B) Watertight maintained contact station C) Watertight selector switch

**Magnetic switches (thermal overload).** The overload relays, both AC and DC, that have thermal overload features, operate by the effect of heat on their trip element There are two general types: 1) the bimetallic strip and 2) the eutectic alloy.

The bimetallic type has a tripping element composed of one or more bimetallic strips (two dissimilar metals with different coefficients of expansion) When these strips are heated they bend or curve, and this movement is utilized to open contacts in the control circuit of the magnetic switch In some designs the bimetallic elements carry the current and break the circuit themselves

The second, eutectic alloy, type of tripping element operates by means of heat, which is generated by the motor current passing through a heating coil (usually a pair) On overload the increased temperature produced by the coil is sufficient to melt a special eutectic (low-melting) alloy, which normally holds the contacts in the closed position, under spring tension and held by a ratchet When the alloy (which soldered the ratchet in place) melts, the ratchet spring causes the contacts to open.

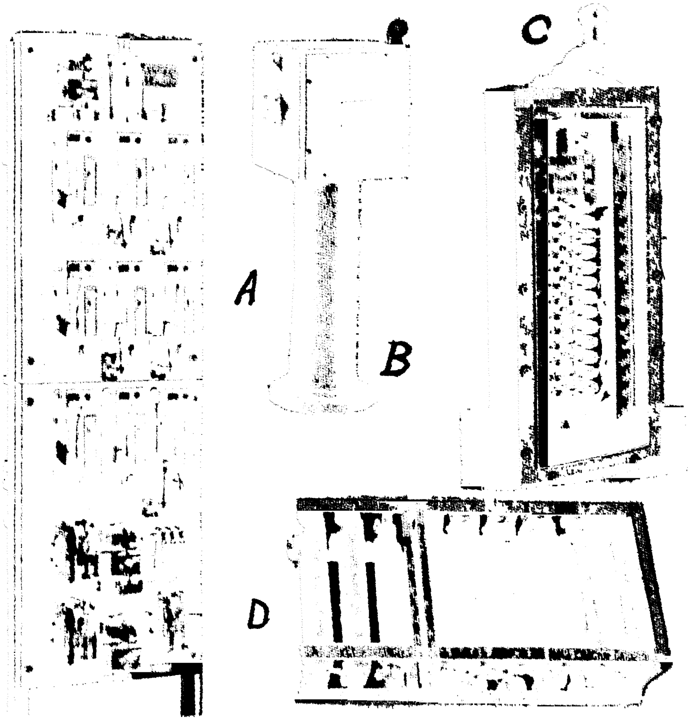


FIG 39 Winch control equipment A) Heavy duty DC control panel for winch and windlass service B) Watertight pedestal type master switch for reversing service C) Waterproof type "A" drum controller for reversing service D) Heavy duty control resistor bank

The heating characteristics obtained in a thermal overload relay of this type coincide very closely with the heating characteristics of electric motors. The eutectic alloy provides a definite tripping temperature which is slightly lower than the danger temperature of cotton insulation.

After the overload has occurred and the relay tripped, it requires a few seconds for the ratchet to be resoldered in place before resetting the relay.

Both the above types of switch have inverse time limit tripping characteristics.

**Magnetic controllers (heavy type).** Magnetic controllers are necessary in the operation of motors where switching of circuit is very complex and quick changes are required; also where automatic features are used, such as overload protection, automatic acceleration, dynamic braking, dynamic lowering and operation of solenoid brakes (Fig. 39). The braking features are used on winches, windlass, capstan, boat hoists, etc. Following are some of the most common controller functions and their definitions.

**Overload protection (OL).** The effect of a device operative on excessive current but not necessarily on short circuit current, to cause and maintain the interruption of current flow to the device governed.

**Inverse time circuit overload protection** is obtained by means of a relay with a series coil and a dash pot construction. This relay permits momentary overloads, but operates if the overload continues for a definite time.

**Automatic acceleration.** Provides for the starting of the motor at a reduced voltage. The cutting out of starting resistance step by step is controlled by relays that operate on the predetermined time sequence which has been found to be best suited for the particular motor application. The time sequence relays are operated by the voltages and currents generated within the motor starting circuit itself during the starting period.

**Low voltage protection. (LVP).** The effect of a device, operative on the reduction or failure of voltage, to cause and maintain the interruption of power to the main circuit.

**Low voltage release (LVR).** The effect of a device, operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit but not to prevent the re-establishment of the main circuit on the return of the voltage.

When the only requirements are "start-stop" or "start-stop-reverse" at constant speed (including reduced constant speed), these controllers are operated by a push-button master switch.

The type of protection determines the type of push-button. For low voltage protection a momentary contact type push-button is provided, and for low voltage release a permanent contact type push-button is provided.

**Jamming relay.** This relay acts on the overload principle. It can be calibrated for a definite current by moving the plunger up and down on the plunger rod (Westinghouse type).

The purpose of this relay is to insert resistance in series with the motor armature in case of stalling or excessive overloads, thereby cutting down the motor armature current to a safe value.

Vital auxiliaries are provided with "low voltage release" so that they will start up automatically as soon as the line voltage is recovered.

On Diesel ships these usually include the following: the fresh water circulating pumps, the salt water circulating, fuel oil pumps, fuel oil centrifuges, the fuel oil booster pumps and the lubricating oil pumps.

On steamships the main circulating and the main feed pumps are included. All pumps controlled by pressure switches, vacuum switches, float switches or any other automatic device must have permanent contact push buttons to insure continuity of operation, and therefore have "low voltage release." These include the fresh water (drinking) pump, sanitary pump, air compressors, priming pumps (for bilge ballast pumps) and the refrigeration compressor.

The refrigeration condenser circulating pump is usually electrically interlocked with the refrigeration compressor, so that it only works when the compressor is working. If variable speed is required, a drum type master switch is necessary for use with the controller.

Current practice tends to group the controllers together or to mount them on a common board rather than to install them at their respective machines. "Hand-Stop-Automatic" selector switches are also used in place of "Hand-Automatic" and a "Start-Stop" push button (Fig. 38).

One method is to provide narrow cubicles in which are installed a number of the lower horsepower motor controllers or one of greater horsepower. These are arranged for mounting side by side.

An opening is provided in the top sides of all the cubicles, except the end ones, and a common supply bus runs through these openings for the entire length of the installation. Each cubicle is closed with a door.

This type is usually front connected. The whole unit (section of cubicles) is fabricated at the factory and shipped complete. This method has been used by the General Electric Company.

Another method is to mount the controllers compactly on a structural steel frame and to provide a terminal board in the rear. The frame is extended in front, and a series of doors are arranged on the frame for access to the controllers. This method is used by Westinghouse.

Both systems have the same general appearance from the front.

"Start-Stop" push buttons are mounted on the doors immediately in front of the controllers they operate. Control rheostats for such equipment as engine room ventilation fans may be mounted on these doors also.

It is the practice to supply magnetic "across-the-line" contactors rather than manual line switches in group control installations where knife switches are permitted, since it makes a better arrangement and avoids the necessity for opening the doors to operate the knife switches. The contactors are of course controlled in the usual way by push buttons.

**Deck winches.** The controllers required for cargo winches (Fig. 39) are designed for reversing and regulating speed when lowering and hoisting, and for dynamic braking when lowering.

Cargo winches are generally in the form of a drum driven through single, double and sometimes triple gear reductions. Nigger-heads are mounted on the reduction gear shaft and are used for topping, etc.

Single gear winches are equipped with compound or series wound motors. Compound geared winches which have a double set of gear reductions, with a clutch to connect one or the other reductions as required, are frequently equipped with motors having a light, restraining shunt winding or with compound wound motors. The restraining shunt winding is to prevent excessive motor speeds where the gear reduction or the construction of the winch is such that the friction load is very light.

The same controller is suitable for use with both compound and series wound motors.

Controllers for heavy pulling, that is for winches, windlass, warping winches and capstan, are of the same general type, all using drum type master switches. The motors vary to a greater or less degree in their torque characteristics. Therefore the controllers are dissimilar in so far as number of relays and details of circuit arrangement are concerned. Otherwise controllers of any one manufacturer have the same general outward appearance.

## WINCH CONTROL

The following is a complete description of the control functions of a typical Winch Control 5-point reversing unit manufactured by Westinghouse. (Refer to Fig. 40.)

### Master Switch in "Off" Position

1) When the main switch is closed and voltage on the line, a current flows through overload relay **OL**, variable resistor **J-F1** and shunt field **F1-F2**, the latter being by-passed by a discharge resistor.

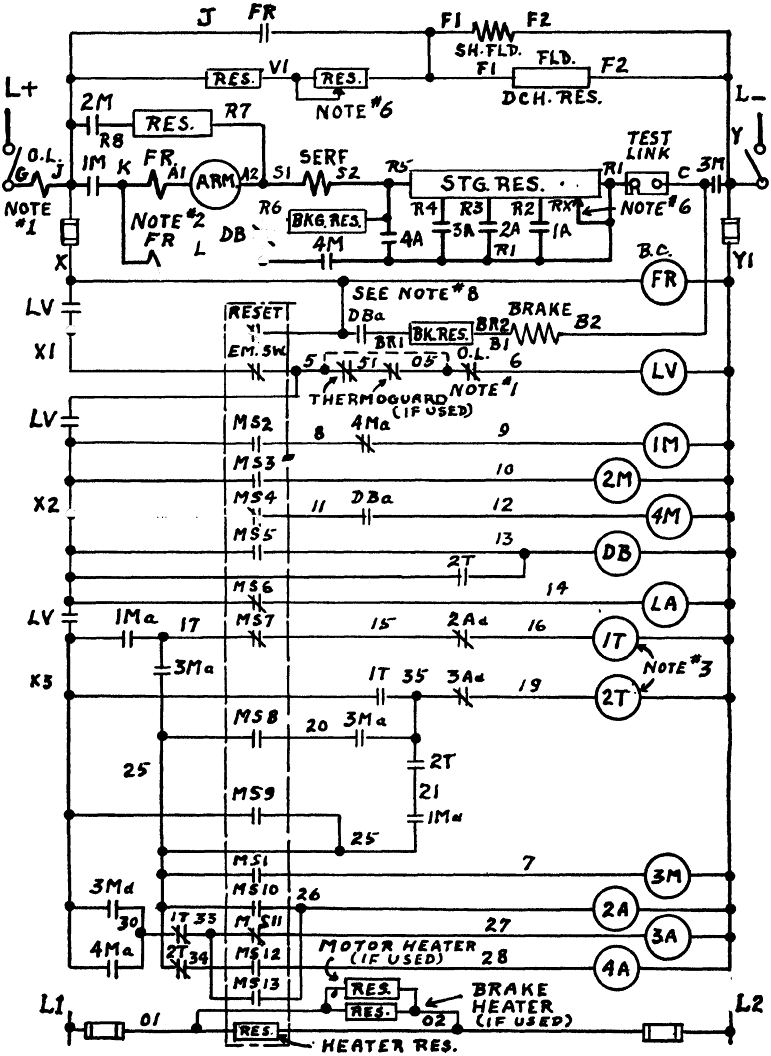


FIG. 40. Wiring diagram of 5-point reversing winch control unit.

2) The blow-out coil of field relay **FR** is energized.

3) The "Reset" contact is closed, energizing low voltage relay **LV** over the emergency switch and overload relay contact. **LV** closes its contacts, by-passing the "Reset" and completing control bus **X-XI-5-X2-X3.**

4) **MS-4** is closed.

5) **MS-6** is closed, energizing and closing contactor **1A**.

6) **MS-7** is closed.

7) **MS-11** is closed—Contactor **1A**, low voltage relay and blowout coil of relay **FR** are energized.

### Hoisting with Slow Acceleration

**First Point.** When moving the master switch handle from the "Off" position:

1) "Reset" opens but remains bridged by **LV**.

2) **MS-1** closes.

3) **MS-2** closes, energizing and closing contactor **1M**. Interlocks **1M** close, the one energizing timing relay **1T**, which closes its "make" contact and opens its "brake" contact. **2T** is now energized and closes its two "make" contacts and opens its "break" contact.

Dynamic braking contactor **DB** becomes energized and opens its main contact. Interlocks **DB** close.

Contactor **3M** now becomes energized, closes its contact and its interlocks. The magnetic brake is now energized and released.

A starting current flows through the overload relay **OL**, contactor **1M**, field relay coil **K-A1**, motor armature and compensating poles, series field, starting resistor **R5-R2**, contactor **1A**, test link and contactor **3M**.

4) **MS-3** closes and energizes contactor **2M**, which closes its contact and by-passes the armature through resistor **R7-R8**.

5) **MS-4** opens.

6) **MS-5** closes.

7) **MS-11** opens.

At standstill, the armature resistance being small, most of the line current will pass through the armature. Running without load, the greater part of the line current passes through resistor **R7-R8**. The maximum speed of the motor is determined by the voltage on **R7–R8**. (Fig. 41–1.)

**Second Point.** **MS-3** opens and trips contactor **2M**.

The motor is now working as compound motor with the same series resistance as before and relay **FR** regulating the field current. (Fig. 41–2.)

**Third Point.**

1) **MS-8** closes.

2) **MS-10** closes and energizes contactor **2A**. Interlock **2A** opens and

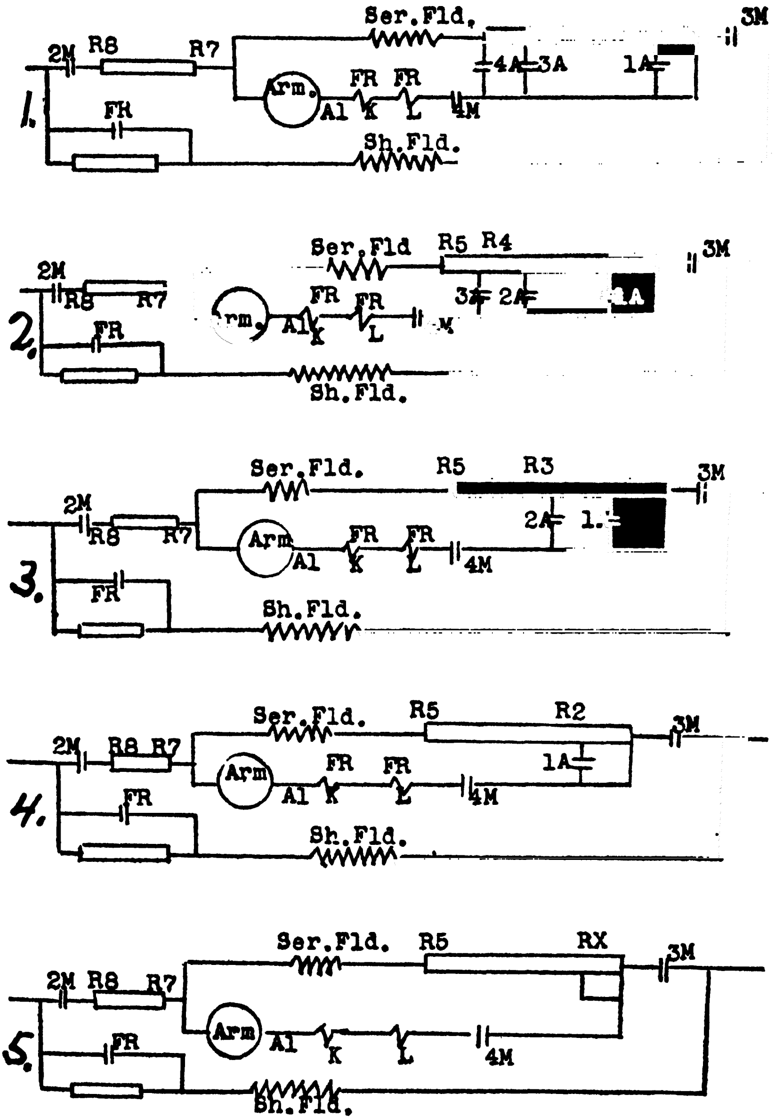


FIG. 41. Control functions of 5-point reversing winch controller.

de-energizes **1T**, which after one second trips, opens its "make" contact and closes its "break" contact.

The starting resistance is now reduced to **R3–R5**. (Fig. 41–3.)

**Fourth Point.** **MS-11** closes and, provided contact **1T** in circuit of coil **3A** is closed, will energize contactor **3A**, which closes its contact and opens its interlock. **2T** is now de-energized and after one second opens its "make" contacts and closes its "break" contact.

The starting resistance is now **R4–R5**. (Fig. 41–4.)

**Fifth Point.** **MS-12** closes and, provided contact **2T** in circuit of coil **4A** is closed, will energize contactor **4A**. **4A** closes its contact.

The motor is now running as compound motor on full line voltage. During the starting period the motor current through field relay coil **A1-K** was high enough to keep contact **FR** closed, providing starting with full shunt field. If the current now decreases, **FR** may trip, depending on its setting, and further speed up the motor by weakening the shunt field. (Fig. 41–5.)

### Lowering with Slow Acceleration

**First Point.** When moving the master switch handle from the "off" position:

1) "Reset" opens but remains bridged by **LV**.

2) **MS-1** closes.

3) **MS-3** closes and energizes contactor **2M**, which closes its contact.

4) **MS-5** closes and energizes dynamic braking contactor **DB**, which opens its contact and closes its interlocks, thereby energizing contactor **4M**. "Break" interlock **4M** opens and "make" interlock **4M** closes, energizing and closing contactor **3A**. Interlock **3A** opens.

5) **MS-7** opens.

6) **MS-9** closes and energizes contactor **3M**. The three interlocks **3M** close. The brake is now energized and released.

7) **MS-12** closes and energizes contactor **4A**.

A current now flows through overload relay coil, contactor **2M**, resistor **R8-R7** and splits into two branches, one through series field and contactor **4A**, the other through commutating poles, armature, field relay coils (**A1-K**) and (**K-L**) and contactor **4M**. Here both branches meet again and continue through test link and contactor **3M**. Due to the low resistance of the series field, only a small voltage is on the armature, which therefore turns only slowly. (Fig. 42–1.)

**Second Point.**

1) **MS-12** opens and trips contactor **4A**.

2) **MS-13** energizes and closes contactor **2A**. Interlock **2A** opens.

The branch current through the series field has been weakened by resistance (R5-R4) and the voltage on the armature raised. The motor speed now increases. (Fig. 42–2.)

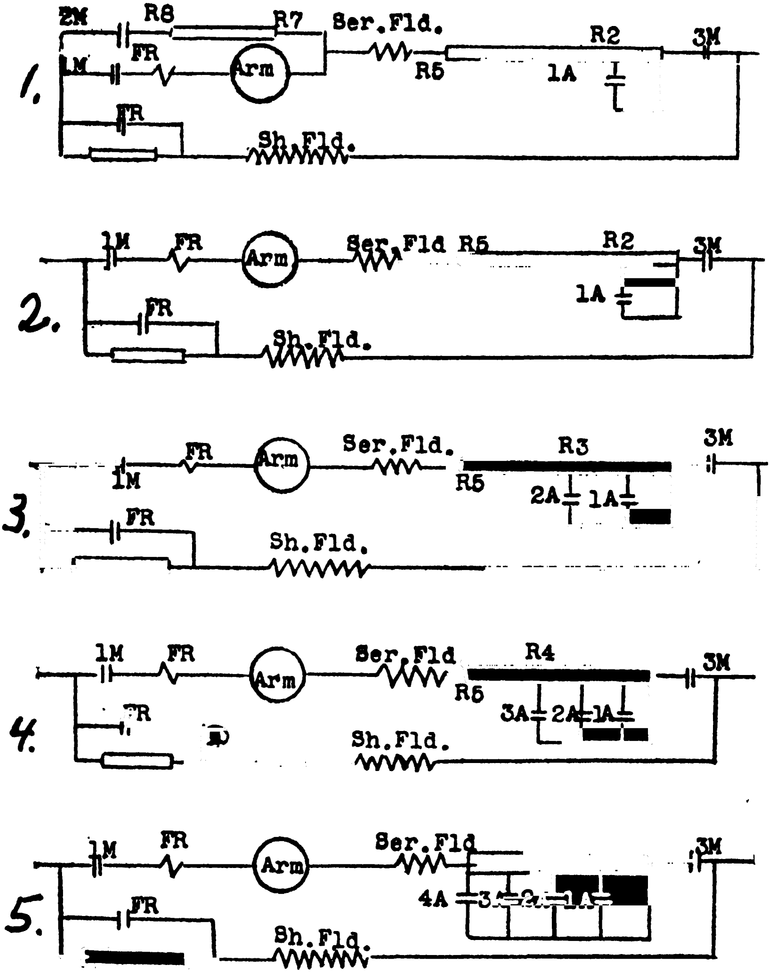


FIG. 42. Control functions of 5-point reversing winch controller.

**Third Point.** **MS-11** opens and trips contactor **3A**. Interlock **3A** closes.

Series resistance in series field circuit is now **(R5–R3)**. (Fig. 42–3.)

**Fourth Point.**

1) **MS-8** closes and energizes **2T**, which closes its two "make" contacts and opens its "break" contact.

2) **MS-13** opens and trips contactor **2A**. Interlock **2A** closes.

**(R5-R2)** is now in series with the series field. **2T** is energized. (Fig. 42–4.)

**Fifth Point.**

1) **MS-6** opens and trips contactor **1A**.

2) **MS-7** closes and energizes timing relay **1T** over **MS-9**, interlock **3M, MS-7**, and interlock **2A**. **1T** closes its "make" contact and opens its "break" contact. The entire resistance **RX-R5** is now in the series field circuit. Both **2T** and **1T** are energized. (Fig. 42–5.)

### Hoisting with Fast Acceleration

If the master switch handle is suddenly thrown over to the sixth hoist position:

1) "Reset" will open but remain bridged by contact **LV** of the low voltage relay.

2) **MS-1** closes.

3) **MS-2** closes and energizes and closes contactor **1M**. The two "make" interlocks **1M** close. **1T** is now energized and energizes **2T**. **2T** picks up and energizes contactor **3M, 3M** closes. Interlocks **3M** close. **2T** also picks up the dynamic breaking contactor **DB**. Interlocks **DB** close. The "break" contacts **1T** and **2T** are now open, and their "make" contacts closed. The brake is now energized and released.

4) **MS-3** closes momentarily, but contactor **2M** has no time to pick up.

5) **MS-4** opens.

6) **MS-5** closes.

7) **MS-8** closes.

8) **MS-10** closes and picks up contactor **2A**. Interlock **2A** opens and de-energizes timing relay **1T**.

9) **MS-11** opens and closes again.

10) **MS-12** closes.

The motor starts with the armature current passing through overload relay coil, contactor **1M**, field relay coil **(K-A1)**, armature and compensating poles, series field, resistor **(R5-R3)**, contactor **2A**, test link and contactor **3M**. Since the starting current will be above the setting of relay **FR**, the motor will start with full shunt field.

11) After one second **1T** trips, opens its "make" contact and closes its "break" contact, thereby energizing contactor **3A**. **3A** closes and its "break" interlock opens, de-energizing **2T**. The starting resistance is now reduced to (**R5-R4**).

12) After a second delay of one second **2T** trips, opens its "make" contacts and closes its "break" contact, thereby energizing and closing contactor **4A**.

The motor is now running with full line voltage, and if the current decreases below the tripping value of relay **FR**, the shunt field will be weakened and the motor accelerate further.

### Sudden Deceleration When Lowering

**A)** If the master switch handle is thrown suddenly from the **second** lowering position to the "off" position:

1) "Reset" closes.

2) **MS-1** opens and trips contactor **3M**. Interlocks **3M** open. Motor main circuit and brake are de-energized.

3) **MS-3** opens and trips contactor **2M**.

4) **MS-5** opens and trips contactor **DB**, which closes its contacts and opens its interlocks. Contactor **4M** trips, opening its contact, closing its "break" interlock, and opening its "make" interlock. Contactors **2A** and **3A** trip and their interlocks close.

5) **MS-7** closes.

6) **MS-9** opens.

7) **MS-12** closes for a moment, but not long enough to pick up contactor **4A**.

8) **MS-13** opens.

The line contactors **1M**, **2M**, and **3M** are all open, the dynamic braking circuit is immediately established, and the mechanical brake set.

**B)** If the master switch handle is thrown suddenly from the **third** lowering position to the "off" position:

1) "Reset" closes.

2) **MS-1** opens and trips contactor **3M**. Interlocks **3M** open. Motor main circuit and brake are de-energized.

3) **MS-3** opens and trips contactor **2M**.

4) **MS-5** opens and trips contactor **DB**, which closes its contacts and opens its interlocks. Contactor **4M** trips, opening its contact, closing its "break" interlock, and opening its "make" interlock. Contactor **2A** trips and its interlock closes.

5) **MS-7** closes.

6) **MS-9** opens.

7) **MS-11** closes.

8) **MS-12** is momentarily energized, but not long enough to pick up contactor **4A**.

9) **MS-13** opens.

The line contactors **1M, 2M**, and **3M** are all open, the dynamic braking circuit is immediately established, and the mechanical brake set.

**C)** When going suddenly from the **fourth** lowering position to "off":

1) "Reset" closes.

2) **MS-1** opens and trips contactor **3M**. Interlocks **3M** open. Motor main circuit and brake are de-energized. **2T** is de-energized but will trip later.

3) **MS-3** opens and trips contactor **2M**.

4) **MS-5** opens.

5) **MS-7** closes.

6) **MS-8** opens.

7) **MS-9** opens.

8) **MS-11** closes and picks up contactor **3A**. Interlock **3A** opens.

9) **MS-12** closes momentarily, but not long enough to pick up contactor **4A**.

10) **MS-13** closes momentarily, but not long enough to pick up contactor **2A**.

11) After one second **2T** trips, closing its "break" contact and opening its "make" contacts. Contactor **DB** trips, closes its contact and opens its interlocks. The latter trips contactor **4M**. "Break" interlock **4M** closes and "make" interlock **4M** opens. Contactor **3A** trips, opens its contact and closes its interlock. Contactor **3A** closed immediately. After a delay, **DB** closed and **4M** opened. **4A** did not close.

**D)** When going suddenly from the **fifth** lowering position to "off":

1) "Reset" closes.

2) **MS-1** opens and trips contactor **3M**. Interlocks **3M** open. Motor main circuit and brake are de-energized.

3) **MS-3** opens and trips contactor **2M**.

4) **MS-5** opens.

5) **MS-6** closes and picks up contactor **1A**.

6) **MS-7** opens and de-energizes **1T**, which will trip later. (**MS-7** will close again after **MS-9** has opened.)

7) **MS-8** opens.

8) **MS-9** opens.

9) **MS-11** closes.

10) After one second **1T** trips. Its "make" contact de-energizes **2T** which will trip later. Its "break" contact energizes **3A** over interlock **4M** and contact **MS-11**.

11) After a second delay of one second **2T** trips, opening its "make" contacts and closing its "break" contact. **DB** trips and closes its contact. Interlocks **DB** open, one tripping contactor **4M**. "Break" interlock **4M** closes and "make" interlock **4M** opens, tripping contactor **3A**. Interlock **3A** closes.

Contactor **1A** closed immediately, **2A** did not close. **3A** closed after one second. **4A** did not close. **DB** closed and **4M** opened after another delay.

## OPERATION OF CONTROL PANELS

**Starting a motor.** In starting up a motor the procedure is as follows:

**Panel type.** See that the starting arm is in the off position, and that all field resistance is out. Close the line switch, or circuit breakers.

Move the starting arm to the first contact button, and then by successive quick movements and pauses, raise it to the full current condition, where it should be held by the no-voltage solenoid. Thirty seconds should be taken for this operation if practicable.

If the machine is variable speed, move the field-resistance lever until the required speed is obtained.

**Controller, drum type.** Move the controller arm slowly from point to point of its travel, allowing the motor to come gradually up to its running speed. A distinct pause at each star wheel release point must not be omitted.

**Contactor panel, automatic type.** Close the line switch, or circuit breakers. Press the start button (or move the master switch lever to "on" position). The machine should work up to its rated speed without further attention, through the operation of its relays.

**Controller, drum type with automatic panel.** Operate the same as a straight drum type.

**Stopping a motor.** To stop a motor it is only necessary to open the line switch or trip the circuit breakers, or in the case of the drum controller to throw the controller arm to the off position. See that moving elements on the panel have all returned to the off, or starting, position.

**Procedure in case of failure to start.** If the procedure outlined in foregoing paragraphs fails to start the motor, proceed as follows, first making sure line switch is open: Using a voltmeter, or an electrician's test lamp, check the presence of voltage at the line switch. Examine fuses and replace any that may have blown. Check over the panel connections for a loose or broken connection, and feel for evidence of burning or local heating. Check connections in the motor leads at panel and motor headboard. Search out the motor trouble.

**Switch and lever operation.** Care should be taken when operating switches or rheostat arms to watch the contact points. Heavy sparking, indicating poor or broken contact, should be investigated and remedied at once. In opening field switches, the blades should be drawn out slowly, allowing the field to discharge with a drawn-out spark. This will prevent the establishment of a high potential in the field coils which might break down a weak point in the insulation.

**Heat as a trouble indicator.** The operating personnel should be constantly on the alert for the presence of unusual or unexplained heat around the control panel. Heat is the primary index of electrical trouble. If excessive heat is noted about the panel, one of two conditions is usually indicated. Either the line leads to or from the panel are too small in current-carrying capacity, or a loose or insufficient contact exists at some connection point. In any panel made by a reputable manufacturer, and subjected to marine inspection, the chance of insufficient carrying capacity in any of the electrical leads or devices on the panel proper is very improbable. Incoming or outgoing cables, however, occasionally are undersized. A loose contact, especially where cable attachments are made, generates considerable heat and will lead to casualty unless the condition is remedied. Such trouble can usually be traced by finding the position of greatest local heat.

**Overload blowout.** If, on starting up a motor equipped with a drum type controller, the fuse or circuit breaker goes out due to an overload, be sure and move the controller arm to the off position before renewing the fuse or resetting the circuit breaker.

**Starting resistance left in.** With a motor controlled by an automatic contactor panel, the operator should determine, after starting the motor, that all the starting resistance has been cut out before he leaves the panel. If all the accelerating contactors do not close, the condition will probably be best indicated by the failure of the motor to build up to its normal speed. Failure of one of these contactors to close will leave some of the starting resistance in the armature circuit, and this, if left in, will soon overheat and burn out.

**Use of wiring diagrams.** Large motors, such as those used for anchor gear, steering gear, capstans, and boat cranes are operated by a master controller. It is necessary that those charged with maintaining equipment of this character be thoroughly familiar with the wiring diagrams of the control circuits, which are usually of a rather complicated character. These diagrams generally contain a table giving the contactors which should be closed for various positions of the master controller, and intelligent use of this table will make it possible to trace trouble readily.

# VI

# OPERATION OF MOTORS AND GENERATORS

**Inspection after assembly, before starting.** After assembling a machine, a final inspection should be made to guard against starting with loose bolts, improper clearance, short circuits, broken insulation, or any damaged parts.

The binding wires should be examined all the way around, especially those on high-speed armatures.

The air gaps should be equal, as measured under poles of the same type, and poles should be uniformly spaced between tips.

The armature clips on both ends are easily bent out of shape when handling, and it is essential that these leads be straightened and uniformly spaced before starting.

The use of two sets of series field connection strips, one connected to each polarity of the machine, usually without the interposition of circuit breakers, requires extreme care in guarding against short circuits. In case of a short circuit between these strips or coils the machine would build up as a series generator with absolutely no protection other than a burn out or shutting down. These parts are carefully designed for ample clearance, and suitable spacing blocks are provided to maintain these clearances; but there is always a possibility of strips or leads being bent out of shape while handling, and a very careful inspection is therefore necessary before starting.

Commutators are frequently fitted with radiating vanes, for cooling, and these vanes should be examined to see that they are properly separated and that the stationary vane guard is assembled with the proper clearance.

Slotted commutators should have the slots cleaned out as an insurance against bridging between segments.

Brushes should be adjusted to an equal tension of 1½ to 2 lb. per sq. in. each on the commutator brushes and about 4 lb. per sq. in. each on collector ring brushes. The brush holder studs should be checked for their alignment with the armature shaft and to see that they are rigidly secured to the rocker. The holders in turn should be securely clamped to the studs. The brushes should fit in the holders snugly, but not so snugly as to bind. Check each pigtail to make sure it is not loose. Such looseness is a frequent cause of abnormal brush heating.

Inspect the lubricating oil system, and see that sufficient oil of the right quality has been supplied.

**Inspection after assembly, after starting.** On starting up, the speed of the machine should be carefully determined to see that proper speed is maintained. No chattering or undue vibration should exist as the load is thrown on or off.

The commutator or collector rings should run true and smoothly without chattering of the brushes, and all sparking should be eliminated.

If a lubricating oil cooling system is provided, the temperature of the inlet and outlet oil should be taken until the running heat is established, and if the temperatures are excessive the trouble should be traced out and remedied before extended running is undertaken. Samples of the oil should be frequently taken, and these should be examined for metal dust from defective bearings and for the presence of dirt in the system. Oil should be renovated until the system runs clean. Examine the automatic oilers and the oil rings and make sure that all are functioning properly.

When the set is in operation make frequent inspections to see that the oil cooler is getting circulating water, and examine the oil to detect any water resulting from leakage in the cooler.

**Starting a generating set.** The steps in starting a generating set are as follows:

Examine both steam and electrical ends to see that all rotating parts are clear. Turn the armatures of small generators one complete revolution by hand.

See that the commutator brush rigging and brushes are clear, and that the brushes react to spring tension.

See that all switches are open and that the rheostat handle is so set that all field resistance is cut in.

Start steam end.

Bring the machine up to its rated speed and see that voltage is normal with the rheostat in low-voltage position.

Test overspeed trip (if overspeed trip has not been tested within one week) by speeding up till the machine trips. Under no circumstance should the machine be allowed to exceed the speed prescribed for the overspeed tripping.

Build up voltage until it is three or four volts higher than the bus voltage.

Throw in circuit breaker.

Throw in equalizer switch (if compound machine).

Throw in negative switch.

Throw in positive switch.

Regulate voltage to divide the load properly. (Indicate by the voltmeters of the two or more machines in operation.)

**Cutting out a generating set.** The steps in securing a generating set are as follows:

Take most of the load off the machine to be secured, by field rheostat.

Trip circuit breaker.

Open positive and negative switches.

Open equalizer.

Put rheostat in position where all resistance is cut in.

Secure steam end.

Blow out armature coils, commutator spider, and air gaps, etc., with compressed air.

**Procedure if voltage fails to build up.** In case a machine gives the opposite polarity to that desired when building up its voltage, separately excite the fields with the correct polarity to reverse the residual magnetism. This is done in the following manner: First, disconnect the brush leads at the headboard; second, on the machine panel throw in—

Shunt field switches, if used.

Circuit breakers.

Common negative switch.

Positive light or power switch.

Momentary excitation is sufficient, so that a moment after closing the positive, the circuit breakers should be tripped, other switches pulled, and the machine again made ready for normal operation. Failure to build up voltage is sometimes due to an open point in the shunt field circuit and sometimes to reversal of the shunt field connection with respect to the armature. A reversed field connection can usually be detected by the residual voltage tending to approach zero when the field switch is closed, and this indicates that the diagram of connection drawing has not been properly followed in the wiring.

If found properly connected, it should be assumed that the polarity is actually reversed. Shut down the machine and separately excite the fields with the correct polarity to reverse the residual magnetism as described above, obtaining excitation from another machine. The resultant polarity must be checked after every separate excitation.

**Constant voltage.** In operating a generator, keep the voltage constant and the load equalized by the field-rheostat. If the voltage is such that an excessively low or high position of the field rheostat is required, the speed of the generator should be checked.

**Checking readings.** Oil-gage readings and bearing temperatures should be frequently checked. The oil should be changed, and filtered or renewed periodically. If an oil-cooling system is installed, constant vigilance is necessary to detect promptly corrosive punctures or leaks in the cooling coils, which allow the passage of salt water into the oil.

**Running at overload.** Most generators are designed for 25% overload for 2 hrs. However, this extra capacity should always be considered as a safety factor and machines should never be habitually run at a greater than rated load. When necessary to operate generators at greater than rated load, inspect all parts such as bearings, field coils, and brush rigging every 5 minutes for overheating.

**Parallel operation.** Any difficulty met in obtaining satisfactory parallel operation is usually due either to differences in compounding or inequality in the resistance of the series field circuits from the equalizers through series fields and cables to the bus. A slight unbalance in the resistance of the two circuits would result in an unequal current flow, so that the machine with the lower resistance series field would carry a greater share of increase in load to the extreme of throwing out the other machine entirely. A simple resistance determination will disclose this trouble, and the remedy consists in shunting part of the flow in the heavier field. Sluggish or erratic governor operation is often a cause of the difficulty, and the remedy lies in a careful disassembly, cleaning, and overhaul of the governor.

**Mechanical balance.** Any appreciable vibration should be located and corrected as soon as it occurs. All rotating parts are carefully balanced at the factory, and an investigation of balance trouble should therefore consist of a careful search for misalignment, sprung shafting, or something chafing the rotating element, before shifting any balancing weights. Brushes sticking in the holders have been know to upset the balance. Balancing pockets in the armature flanges, in which lead can be peened, are provided for correcting any unbalancing of the armature.

**Effect of brush position.** After running a short time, the appearance of the brush faces will indicate whether the brushes will soon wear to a proper fit over the entire surface or not. Any of the brushes showing a fit over only a very small area should be sandpapered again. It will be found that reliable results in compounding tests cannot be obtained before the brushes are all thoroughly fitted. Shifting the brushes around the surface of the commutator has an effect on both the compounding and commutation. In a generator, the armature current reduces or increases the main field magnetization, depending on whether the brushes are ahead of (shifted in the direction of rotation) or behind the true neutral point, thus having considerable influence on the compounding. In order to prevent sparking, the brushes must be held in such a position that the armature coils short-circuited by the brushes are under the influence of the commutating poles, but occasionally shifting from an exact center to produce slight changes in compounding is permissible. Even the most careful setting with the tram is subject to slight errors, and as a final adjustment, when working to very close limits, slight changes in brush position may be necessary. On a machine that is running, take care when shifting brushes to guard against raising the yoke out of its support, which would pull the lower brush holders into the commutator and cause serious damage. In spite of these instructions, however, machines should habitually be operated with the brushes set at the neutral point at which the machine was initially compounded and adjusted. The necessity for a departure from the manufacturer's punch marks is a trouble indicator.

**Sparking.** Sparking may occur at the brushes for any one of a number of reasons which are itemized and for which remedies are discussed on page 111. As soon as sparking occurs the conditions which cause it should be rectified, as these conditions will rapidly become aggravated.

**Switchboard manipulation.** The same method of operating switches at the switchboard should be employed by all operators.

## CARE

**Cleanliness.** Keep both the interior and exterior of a generator or motor free from water, salt, lint, dust, dirt, and particularly oil. Do not allow oil to enter the machine with the cooling air and thus be deposited on the windings. An excessive accumulation of dirt may eventually ground the coils and burn them out. Dirt, aside from restricting the air flow, is a heat insulator.

Particular care should be taken to guard against carbon dust from brushes and copper dust from sanded commutators.

When cleaning a machine, care must be taken not to crowd dirt into narrow spaces between conducting parts, or in the air ducts.

Care must be taken in filling oil containers on ring oiling motor bearings that the oil level is not so high as to result in leakage along the motor shaft. Filling these bearing oil containers too full causes overflow into brush rigging and lower field coils and creeping of oil into interior of spider and thence to commutator and windings.

The penetrating and damaging effect of oil in electrical apparatus is universally known, and must always be carefully guarded against. The presence of oil inside the main motors is chiefly caused by the following:

Dripping from machinery, shafting, or other gear installed over the main motors, the oil gradually seeping into the casing through the handhole plates or other joints.

The ventilating system supplying the cooling air, which always contains oil vapor, resulting in a gradual accumulation of oil inside the motor.

**Dirt and dust in coils.** Should dust or dirt be lodged with oil on the coils, remove it by means of a cloth dampened with clear carbon tetrachloride (Pyrene liquid), taking care not to touch the steel parts, as corrosion will develop due to a combination of moisture and carbon tetrachloride on steel. Carbon tetrachloride should not be used in confined spaces where the ventilation is poor, due to the harmful effects to personnel, resulting from the accumulation of toxic volatiles. Remove all salt deposits from the machine. Clean rags, or preferably cheesecloth, should be used in all windings. The use of any material which deposits lint must be avoided.

**Painting.** The use of paint on the insides of field frames and housings eventually results in paint getting on field coils, leads and brush riggings. As ordinary paints usually contain materials of a conducting nature, such as white lead, they must not be used in the vicinity of windings or any live parts. This precaution applies particularly to open motors, brush rigging and electrical panels. On the above-mentioned parts the best grade of insulating varnish should be used. All fiber insulating distance pieces and bushings should be carefully cleaned and scraped and coated with insulating varnish. Electrical leads should be properly served, and should always be painted with insulating varnish.

**Tightening bolts.** All bolts should be gone over occasionally to keep them tight, particular attention being given to the bolts used to clamp any insulation. Fiber insulation, used around brush holder brackets and collector rings, and wooden spacing blocks are sometimes used in supporting connection strips, and as this material is subject to considerable shrinkage, the bolts must be tightened frequently until the insulation is thoroughly seasoned. In setting up on brush stud nuts always check the stud alignment, as any throw of the end brushes ahead or back of their normal position will cause sparking in various degrees. Unless a commutator shows evidence of loose bars the commutator clamping bolts should not be disturbed. Serious distortion of the clamping rings and segments is sometimes caused by excessive tightening of the commutator clamping bolts, so considerable care must be exercised in adjusting them.

**Commutators, collectors, and brushes.** Most of the sparking experienced after a machine is in operatoin is due to mechanical defects, such as rough or eccentric commutators, or brushes not riding properly. If the commutator and rings are sufficiently true and smooth, the brushes will feel "dead" when the machine is at normal speed. The brushes should be staggered to cause the commutator to wear evenly. If this is not done, the commutator will wear into shoulders and ridges which will finally require turning down.

When fitting new brushes, care should be taken that the brush fits its holder loosely enough to permit up and down motion, but not so loosely as to cause excessive wobbling. Commutator slots must be cleaned out occasionally to keep all the mica well below the wearing surface, special care being taken to eliminate all projecting fins or slivers. The use of oil on commutators is unnecessary, except in rare instances where some of the older types of hard carbon brushes are used. With most of the modern brushes of a graphitic nature, oil is actually detrimental to commutation. Besides the effect on commutation, oil, vaseline, or other commutator lubricant should be avoided on commutators, as such lubricants have a tendency to work into the side mica, causing insulation breakdown and short circuits between segments. Commutators are slotted in order to use the modern graphite brushes, which have very desirable current-carrying and lubricating characteristics, but which will not wear mica down evenly with the copper. In general, therefore, it never is advisable to lubricate slotted commutators.

The collector rings of machines using brushes of a metallic composition run at higher pressures than commutator brushes give, and best results are obtained on collector rings if a slight amount of oil is applied occasionally with a small brush or canvas swab. Just enough oil should be applied to lubricate slightly the brushes and produce a polish on the rings. Brush-holder level arms should be inspected occasionally to see that the springs give uniform tension, and the brushes should be moved up and down to insure that they work freely in the boxes. An accumulation of dust has been known to settle in the clearance space around brushes and embed the brushes so tightly in the boxes as to prevent their removal without breaking. Brush holders are so made that the spring tension can be easily adjusted to keep the brush pressure uniform. As mentioned on page 186, the springs on the commutator brush holders should be adjusted to give 1½ to 2½ lb. each, and on collector rings approximately 4 lb. Uniform brush pressure is a very important factor in maintaining successful collection of current from the commutator and collector rings.

**Cleaning windings.** A compressed air jet, or even a hand bellows, is a most effective means of cleaning the windings of rotor or stator and for dislodging the metallic dust which accumulates between the commutator segments. Frequent use of such a device will save much expensive overhaul. Before using the air jet, the freedom of the air from water must be assured, and care must be taken to avoid the danger of driving grit into bearings. (See the section on Maintenance.)

**End windings.** Once a year clean the end windings thoroughly and apply a coat of air-drying insulating varnish. Special care should be taken in the application of air-drying insulating varnish to windings to insure that air passages through the winding are in no way restricted by uneven distribution of the varnish. This varnish may be sprayed on by using compressed air in connection with an atomizer. In varnishing windings care should be taken that no varnish is blown into electrical contact surfaces where it will tend to insulate them and prevent current from flowing. During the varnishing operations all brushes should be removed and the commutator should be wrapped with canvas.

**Air ducts.** Keep the air ducts free from dirt. Any restriction will seriously interfere with the flow of the cooling air and cause excessive heating.

**Prevention of moisture when shut down.** If an electrical machine is to be shut down for any period exceeding 24 hours, and it is provided with heating coils, the dampers at the air inlet and outlet ducts should be closed and steam turned into the coils. This will heat the interior of the machine several degrees above the room temperature, and so prevent the accumulation of moisture on the windings and the working parts. Where electrical heaters are provided they should be used in preference to steam coils. Their use is especially necessary on large idle motors or generators during long periods of damp weather. Care must be taken with any drying-out heaters that the heat is evenly diffused and that local spot heating does not result. Many machines, due to peculiarities of location, are liable to an excessive moisture precipitation. In such cases, the use of an ordinary portable 40 to 60 watt lamp placed well within the frame and the whole covered with a tarpaulin is recommended to produce the necessary temperature rise where special heating facilities are not provided. Free circulation of the air through the windings should be assured unless these precautions are taken.

**Causes of over-heated bearings.** Overheated bearings may result from a number of different causes, among which the following are most frequently found:

Bearings out of alignment. Insufficient oil. Poor-grade oil. Dirt or grit in oil. Gummed-up leads. Poorly fitted bearings. Bearings too tightly set up. Scratched or corroded journals. Overload. Conduction from overheated electrical parts.

Dirt may cause the gage glass to indicate oil when none is present, and a clogged top vent will cause the same effect; oil rings will wear out of round and fail to rotate; lack of end play will cause binding or heating, the trouble becoming aggravated as the shaft expands; a bent shaft will cause vibration and grinding at the journals. All these troubles should be guarded against by frequent intelligent inspection. Until a machine is available for overhaul, overheating may often be checked by the use of a liberal supply of fresh, cool oil, or in emergency by the use of water, taking care to keep the electrical parts clear of either oil or water.

Inspection will usually disclose the particular trouble, and the remedies are obvious.

**Sparking and its remedies.** Sparking at the brushes indicates a condition which should be promptly remedied to prevent serious trouble. It may be caused by any one of a number of conditions, or their combinations, and oftentimes the character of the sparking will indicate the underlying trouble. The following list of symptoms is offered as a tentative guide in trouble finding, though it should not be accepted as final:

Incandescence of the carbons. High, white spark under one brush. Periodic sparking. Blue, snappy sparks. Ring of fire. Continuous heavy sparking. Sparking varying with resistance. Continuous light sparking. Sparking on starting up. Sparking at heel or toe of brushes.

**Brush rocker ring at the wrong place (off neutral).** Set the rocker ring to the square mark on the frame.

**Brushes wrongly spaced** may be caused by a blow either to the brush holder or to the rocker ring, bending either out of true, or may be due to a poor setting in tightening of the brush-holder stud. A convenient method to test spacing is to cut a strip of paper until it fits around the surface of the commutator, then fold it in divisions corresponding to the number of rows of brushes. Place this template around the commutator, and check the brush edges against the creases.

**Poor brush contact** may be due to high spots on the brushes, to the binding of the brushes in their holders, or simply to varying spring tension among the different brushes. With any of these defects the result is to reduce the effective brush area, forcing the actual effective area to carry excessive current. This will induce heavy sparking and often heat the overloaded carbons to incandescence. In the first case, place a piece of sandpaper face up on the commutator, and by revolving the commutator with the brushes held in firm contact, grind the faces down to an even bearing surface. In the second, clean the holder, and clear the sides of the carbon of fins and ledges. In the third, even up the spring tension all around, bearing in mind that the brushes underneath should be set up slightly tighter than those on top to balance the action of gravity.

**Commutator dirty or rough.** The commutator should be kept clean by wiping with light canvas, cheesecloth, or woolen cloth, care being taken not to allow any threads to lodge on the brushes or between the segments. If carbon dust and oil collect on the commutator, they will give trouble. Once a dull, glazed, brown-black finish has been obtained on the commutator, very little further roughening will occur. It should be the ultimate aim of the operator to develop this clean smooth chocolate color on commutator bars. Sandpaper should be used very lightly on the commutator, if at all, and emery cloth must never be used, as emery is a metallic conductor which, if lodged between segments, will short-circuit them. If it does become necessary to use sandpaper to smooth the commutator, the sandpaper should be fitted in a wooden block which has been shaped to the proper curvature, and should be held firmly against the surface and drawn in the direction of rotation of the armature. Projecting mica insulation will not yield to the action of sandpaper, and must be turned down with a light cut in a lathe, or by a commutator grinder, a finish being given with fine sandpaper.

**Grinding a commutator.** Grinding at or near full speed is the best method of truing or smoothing a commutator or collector, and if facilities are available for grinding, this method is always preferable to using a lathe-cutting tool. In grinding, a large number of very light passes must be taken to insure a true cylindrical surface. Any undue haste or crowding of the grinding wheel will result not only in a rough surface, but often in a noncylindrical shape. During the grinding operation all windings should be protected from the deposit of copper dust, the field coils being protected by a stationary guard and the armature fitted with a canvas head securely bound on the commutator and armature surfaces. The ventilating spaces under the commutator may be protected by stuffing them full of waste, care being taken to remove this waste when through grinding. After grinding, the machine should be thoroughly cleaned and the commutator slots gone over with a sharp tool to remove any copper dust or bridges, and to smooth up the edges of the segments.

**Copper embedded in the brush.** A bright sparking appearing under one brush and gradually cutting a groove in the commutator is due to a particle of copper which has become embedded in the brush. This reduces the local contact resistance, causing an abnormal current to pass at this point, which is shown by the spark. Remove the copper by scraping the brush face with a knife and sandpaper the brush to a fit.

**Commutator bars, loose, high, or low.** A single bar in the commutator which is out of the cylindrical surface will cause the brush to vibrate, producing poor contact and consequent sparking. As soon as possible, the machine should be stopped, and the bar should be tapped back into place with a block of wood and a mallet. A low bar is seldom found. It usually indicates a slacking up of the commutator and bolts, and an entire readjustment of the bars. If the commutator bars are loose, the nuts on the end should be tightened up, and the whole commutator be given a light cut.

**High mica.** Sometimes the mica between the segments is of such a hard quality that it will not wear down so rapidly as the copper, the effect being that of a series of high bars—vibration of the brushes and consequent sparking. The only remedy for this condition is grinding or using the turning tool, as sandpaper will not cut the mica. A large percentage of commutator troubles may be eliminated by "undercutting" the mica insulation. The process is easily performed by a good and careful mechanic, and accomplishing it is the only positive way of eliminating "high mica" troubles. In merely cleaning out the slots of a properly undercut commutator a thin wooden wedge should be used in preference to a sharp steel instrument. In cutting out high mica insulation a steel cutting tool will of course be necessary.

Defective coils fall into three classes:

**Open-circuited coils.** The trouble is usually found to be a loose connection between the armature coil and the commutator bar. The condition is indicated by a blue, snappy spark, just as the bar leading to the defective coil passes under a brush. If the contact is definitely broken, the spark will hold between the bars, producing a ring of fire around the commutator and burning the mica between the segments. The connection may at times be broken, and at other times give sufficient contact to carry the current without trouble. This will give rise to intermittent sparking. A case is on record where excessive sparking was caused by a fracture of the laminated copper risers connecting the commutator bars with the coil terminals. This fracture was not apparent on visual examination, and was only found after a Wheatstone bridge resistance determination had traced down the bad point. To locate accurately an open-circuited coil, if inspection does not disclose it, remove all bushes from the commutator except one pair. Connect across these brushes leads from the lighting circuit, with a lamp in series, or use two dry cells to furnish a low voltage supply. With a low reading voltmeter, take readings from bar to bar around the commutator, rotating the commutator slowly so that the bars will be successively under the brushes. If readings are the same all around, no trouble is indicated. If the reading across one coil is equal to the voltage across the brushes and all the other readings are low and of equal value, the open circuit is found. An aggravated condition will often be indicated by local high temperature, and sometimes by an actual burning of the commutator bar attached to the defective coil.

**Short-circuited coils.** A rough test for this condition consists in holding a piece of iron (screw driver or other tool) a few inches from the end windings. The iron will throb each time the short-circuited coil passes. To locate the defective coil accurately, test as described in the preceding paragraph, using the low voltage method. In this case a zero reading or a reading materially less than the other equal readings will indicate the trouble. This condition is also accompanied by local high temperature and often by burning of the commutator segment.

**Grounded coils.** The existence of this condition may be determined by reading the armature resistance to ground with a megger. At least one-half megohm is required for proper operating condition and the initial insulation resistance to ground is 1 megohm. If a ground is indicated by this general test, use the low voltage test as described above, by connecting one voltmeter lead to the shaft and the other to each segment in turn. If the readings are the same (practically zero), the armature is not grounded. If grounded, the readings will vary, and there will be two segments with practically zero readings. One of these is the real and the other a phantom ground. Mark both with chalk, rotate the armature a few degrees, and again make the test. The real ground will read on the same bar as before, while the phantom will shift to another bar.

**Eliminating moisture grounds.** Baking will often remove grounds, and a jury oven may readily be rigged by using a box or even a tarpaulin for the oven; anything big enough to cover the armature, or even the whole machine. By using a lamp bank, maintain a temperature of from 135° to 150° F., and take megger readings to ground until the insulation resistance reads one-half megohm or better. This may take several days. If the field coils have moisture grounds, the armature may be disconnected and a properly regulated current applied to the field windings for drying out. A thermometer should be placed in the windings to ascertain the rise in temperature, which, by properly adjusting the current, should be at a slow and uniform rate.

If the trouble cannot be readily remedied, the armature should be replaced by a spare and the grounded armature repaired.

**Temporary coil repair.** In emergency or lack of a spare, temporary repair may be effected by disconnecting the broken coil from its segments and insulating the loose ends. The disconnected segments should then be connected by bridging them with a piece of strip copper of sufficient size to carry the current, soldering, if practicable, to secure a good connection at the segments.

**Overloading.** An overloaded machine will spark heavily. If sparking starts suddenly without apparent reason, the controlling ammeter should be read first of all. While all marine machines are designed with an overload factor, they should never be run in this condition except temporarily and with good reason. Temperature rises under overload are over the design limits and will soon break down the insulation. When an enclosed motor is found running hot, it may be opened to cool it down, but care should be taken to see that it is not left open where dust and moisture may be collected. If overheating occurs too often, the motor is either overloaded or something is wrong, and the trouble should be searched out and corrected. Checking ampere load and speed after each overhaul cannot be overemphasized. This practice greatly assists in locating trouble and familiarizes operators with the use of instruments and acquaints them with normal conditions.

**Dirt between bars.** Sparking is sometimes observed when starting up a machine which has not been properly cared for, the sparking often taking the form of a ring of fire around the commutator. Dirt, which has collected between the segments, is usually the cause, with the dirt forming crosses which are burned out as the voltage increases. This always indicates a poorly cared for machine, and unless remedied, the insulation will eventually be burned out.

**Weak field.** A weak field will ordinarily cause a machine to spark. It may be caused by loose field contacts or by burned-out coils in the field. A variable contact in the field will cause sparking, as resistance is increased.

**The yoke.** If for any reason a brush yoke is to be removed, the yoke, the casting to which it fits, and all connections should be plainly marked, so that they may be readily replaced in their original positions. The proper position of the yoke is determined when the generator or motor is tested at the factory and should be plainly marked. However, as these marks correspond to the full-load position, and as the motor or generator may run at less than full load, it may be necessary to shift the position of the brushes slightly to secure the best commutation. This latter statement does not apply to interpole machines, the brushes of which do not require shifting for various loads, the neutral position for the brushes being marked.

**Handling an armature.** The greatest care must be taken when handling an armature. Wrap armature and commutator with canvas before handling. It must not be allowed to bump while being lifted. Before lowering it on deck, always provide a pad or thickly folded tarpaulin for it to rest on. It is always preferable to rest the shaft ends on blocks or trestles, but in using such blocks avoid taking any weight on the windings or commutator. In rigging slings, pass them near the shaft ends and use a spreader to prevent sliding into the commutator or windings. While the armature is clear of the frame do not allow small pieces of iron, such as bolts or filings, to attach themselves to the pole pieces. Carefully examine both armature and frame before replacement to be sure that both are free of foreign matter.

**Setting the armature for concentricity.** The frame should be concentric with the armature after the machine has been assembled. To test for concentricity the air gap should be measured in the following manner: Examine the bearings first and see that the clearances are not excessive. Excessive drop should be remedied before proceeding. Use a tapered stick about 5 in. long, ⅜ in. wide, and ¼ in. thick at one end, tapered down to 1/16 in. at the other. Graduate one of the tapered faces at each ½ in. along its length. Now number the poles for reference and take a reading between each pole (main) and armature at front and rear of the machine. Rotate the armature ¼ turn, and take another series of readings. Repeat this until 4 sets of readings are obtained. Divide the sum of the readings under each pole by 4, and compare the results, determining thus the direction in which the frame must move to equalize the readings. Now release the frame holding-down bolts, jack it up by the elevating screws usually supplied for the purpose, and insert or withdraw liners under the feet as necessary to give the proper direction of movement. With the liners set, back off the elevating screws, set up loosely all around the holding-down bolts, tighten them equally, then set them up very tight. Recheck the gaps and, if necessary, repeat the operation. After such an adjustment, remember to readjust all brush tensions.

**To remove a pole.** To remove a pole it is not necessary to remove the armature. First disconnect the field windings, and then remove the bolts which secure the pole to the frame. Slide the pole out with its winding. In replacing, be sure to put back under the pole only the same number of liners or shims of high permeability sheet iron that were found there upon removal. After setting up, check the air-gap measurements as described in the foregoing paragraph. When a spare pole has been installed, it may be necessary to add or remove liners in order to rectify the air gap.

Electrical machinery should not be started after an overhaul until after an inspection has been made for loose bolts, improper clearance, short circuits, broken insulation, tools adrift, etc. The speed of the machine after starting, likewise ammeter readings of field and armature, should be checked with the instruction book and recorded.

After a machine has been started, if running temperatures are excessive, the trouble should be traced and rectified before extensive running is undertaken.

Machines should not be run in excess of their designed rated load except in emergency, and the upper limit of 25% over-load should never be exceeded.

The designed r.p.m. of machines should not be exceeded. The overspeed trips of turbine-driven generators should be set at 10% above the normal operating speed.

If brushes are shifted in a machine that is running, great care must be taken against raising the yoke out of its support, thus pulling the lower brush holders into the commutator and causing serious damage.

Examine and rectify at once conditions causing sparking, as these conditions, if not rectified, will rapidly become aggravated.

Keep the interior and exterior of machines free from water, salt, lint, dust, and particularly oil.

Gasoline or other inflammable liquids should not be used about electrical machinery, where a spark may cause ignition.

Emery must not be used on electrical machinery. Sandpaper should be used instead.

If the emergency governors fail to trip at approximately 10% in excess of the normal speed, the machine should not be run until the governors have been regulated.

All protective devices for electrical machinery, panels, circuits, etc., such as fuses, circuit breakers, no-voltage and overload releases, etc., should be kept in proper working order and at their designed settings at all times.

Covers for all screw-type fuse boxes, junction boxes, etc., should be kept on and screwed down tight; lever-type boxes should habitually be kept closed; gaskets on all boxes should be kept in good condition and free from paint.

The entire electric installation in spaces containing inflammable vapors should be tested for grounds and defects remedied before sending men to work in the vicinity thereof. This test for grounds should be made from a switchboard outside the fouled spaces and repairs made with the circuit dead.

For protection of turbine exhaust casing against excess pressure a number of different devices are fitted on different vessels. Such devices include: Sentinel relief valve which should be set to lift at 18 lb. gage; relief valve which should be set to lift at 20 lb. gage; spring-loaded exhaust valve which should lift at 2 lb. in excess of auxiliary exhaust line pressure; and steam-and-exhaust valve interlock of such design that the steam valve cannot be opened until the exhaust valve is open and exhaust valve cannot be closed until steam valve is closed.

Examine each running generating set as to the condition of the commutator, the lubricating system, the governor action bearing temperature, vibration, etc., once a day.

Each generating set not in use should be turned over daily.

Each generating set should be run at least 30 min. weekly to insure that nothing has developed to impair its efficiency.

During the course of this test the generating set should, when fitted with a spring valve to the atmospheric exhaust, be run noncondensing for a sufficient time to insure that this valve is in first-class condition and capable of operating automatically against the back pressure for which the spring is set. On turbo-generating sets, test the emergency governors and see that they trip at about 10% above the normal speed. Test other protective devices associated with the sets for positive action, including the shunt trip on the generator circuit breakers and back pressure trips if fitted.

Examine each running motor thoroughly at least once daily, noting specially the condition of the commutator, oil cups and rings, bearing temperatures, etc.

If time is available, test each motor circuit for grounds daily. In making the test, place the controller arm on the first starting position, so as to include the motor and all resistance. If a ground detector voltmeter is installed, the presence of a ground can be determined at the switchboard. Individual circuits can then be pulled out until the ground disappears. This method will isolate the troublesome circuit and regular use of the detector will tend to keep the entire wiring free from grounds.

Operate each idle motor once each week for at least 10 min., noting its operation and insuring that nothing has developed which will interfere with its efficiency.

Check the speed of each motor against its name-plate data from time to time.

Test each control appliance actually in use through its cycle of operation to insure that it is functioning satisfactorily.

Note the satisfactory operation and condition of control appliances and pay special attention to the heat conditions on and around the control panel.

Investigate the conditions behind those panels which are placed in such position that their backs are ordinarily inaccessible. If the panel is clean and shows no local heat, the insulation resistance of good value, and operation satisfactory, the panel should not be dismounted. If these conditions are not fulfilled, it should be pulled down to correct any defects and to clean it.

# VII

# ELECTRIC PROPULSION

## TURBO-ELECTRIC DRIVE SYSTEM (GENERAL)

Turbo-electric drive, considered from the standpoint of a single complete unit (Fig. 43), consists of a turbine-generator, a propelling motor, and a control equipment for switching the electric connections during maneuvering operations.

In merchant-ship work, the electric apparatus, when of the alternating-current type, has usually been connected 3-phase. To reverse the direction of rotation of the propelling motor, it is necessary only to transpose 2 of the phases. This is easily accomplished by reversing contactors, which are operated by means of a single lever situated on the control panel.

On twin-screw ships having 2 main turbine-generators, cross-tie busses are provided so that both motors can be paralleled on either main generator. The 3 cables that connect the generators to the motors, and the cross-tie busses, comprise the entire main current-carrying system.

The field circuits vary with the type of propelling motor used. With the induction motor, it is necessary to supply excitation only to the field of the generator from a single potential source. When the synchronous motor with a squirrel-cage starting winding is used, excitation is supplied to the generator field usually at twice normal voltage during starting, and to both the generator and motor fields at normal voltage after the motor has become synchronized.

The field circuits are provided with contractors for opening and closing the lines, and with rheostats for regulation of voltage. The field contactors are operated by means of a single level, and the rheostats by means of handwheels, which are all situated on the control panel.

The DC supply for exciting the field circuits is usually furnished by an auxiliary DC generating set.

Variation in the propeller speed on electrically propelled ships using AC machinery is accomplished by adjusting the speed of the main turbine-generator.

The data that can be obtained on turbo-electric drive ships are of a most valuable nature. The meters on the operating panel indicate the power being developed; and this reading, taken in conjunction with propeller revolutions, draft, wind and sea conditions and fuel consumption, permits logging complete and accurate data regarding the propulsion and economic characteristics of the ship.

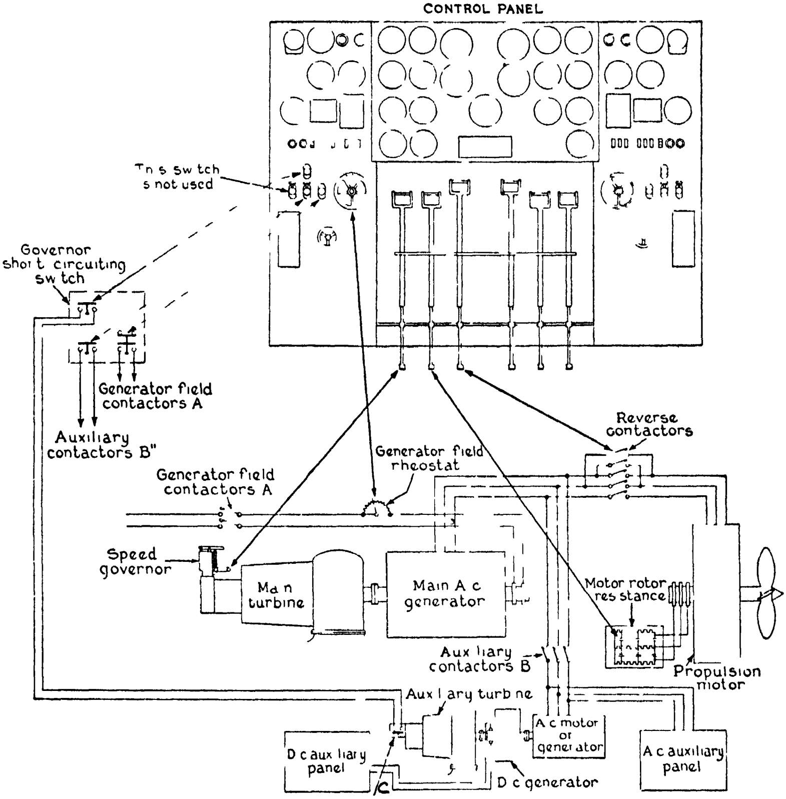


FIG 43 Diagram showing the connections between control panel and propulsion equipment for a twin-screw ship with wound-rotor induction motors. The main units also furnish auxiliary power (Only one propulsion equipment is shown.) *C* is an automatic switch operated by the auxiliary turbine speed governor. The contacts of the switch are closed when the set is running at normal full speed. When the speed drops below about two-thirds normal, this switch opens and causes the auxiliary contactors *B* to open, thereby disconnecting the auxiliary set from the main set.

The operation of turbo-electric drive ships is quite simple. Operation of the levers during maneuvering is easily understood, and the adjustments are readily made.

Two systems of turbo-electric drive are in use in the merchant service. They differ in respect to the type of motor used. The types which are used are the synchronous motor, with squirrel-cage type starting winding, and the induction motor. Synchronous motors are used almost exclusively on large passenger and combination passenger-cargo ships, whereas induction motors are used principally on ships designed for special service.

The stators or armature windings of motors of both types are similar. The difference between the two types is in the rotor construction and the method by which the rotor windings are excited. (Compare Figs. 29 to 31.)

In the **induction motor**, the rotor revolves at a slightly less speed during normal operation (approximately 1%) than the revolving flux in the stator, thereby cutting magnetic lines of force which in turn cause a current to flow in the rotor windings. To obtain good starting torque, or high torque at large slip values, requires a high-resistance rotor winding, whereas efficient operation at running speeds and normal slip requires a low-resistance rotor winding. This is accomplished in three ways: 1) through the use of a double squirrel-cage winding in which one of the windings is of the high-resistance type and the other of the low-resistance type; 2) by a combination squirrel-cage winding and form-wound winding in which the latter is provided with external resistance that can be short-circuited after the motor is up to speed; and 3) through the use of a single-wound type of winding in which external resistance is supplied that can be regulated during starting and short-circuited when operating at normal speeds and slips.

In merchant ships of special type using the induction motor, it has been general practice to apply motors of the wound-rotor type with external resistors. These resistors are used for starting and also for obtaining lower speeds than those corresponding to the frequency. One of the attributes of this type of motor is that it can be pulled in at a relatively high percentage of its normal running frequency. This permits power to be furnished by the main turbine-generators simultaneously for propulsion and auxiliary purposes and for obtaining low propeller speeds during maneuvering without materially affecting the speed of the auxiliaries.

The **synchronous motor** possesses the characteristics of high efficiency and unity power-factor, but does not lend itself readily to the pole-changing feature of the induction motor. Nor can its speed be lowered to a value below that corresponding to the speed of the revolving flux in the stator windings. On account of the fixed electrical gear ratio between the generator and motor the principal field of application is in large merchant ships that operate on schedule speeds. The fact that the excitation current for the motor field is furnished from an outside source relieves the main generator of furnishing this magnetizing current, permits the system to operate at unity power-factor, and in turn reduces the size of the main conductors and also the size and weight of the generators. The synchronous motor also has a somewhat more open type of rotor construction and larger air gap, and is lighter in construction. Emergency repairs can also be made to the rotor windings without withdrawing the rotor.

The synchronous motor without a squirrel-cage winding has practically no starting torque; hence use is made of a squirrel-cage type of bar winding for starting. The pull-in is also made at somewhat lower speed than with the induction motor, being accomplished at approximately 25% normal value. This feature therefore removes the possibility of using the main power plant both for propulsion and auxiliary power purposes, except within definite speed limits, and necessitates provision for an automatic change-over of auxiliary load to a standby generating set when the speed of the main unit drops below a predetermined point.

Motors of both types have been widely applied; the induction motor on all of the well-known battleships and airplane carriers, on self-unloading bulk-freight carriers, on car ferries, and on yachts. The synchronous motor with squirrel-cage starting winding has been applied on all modern passenger ships and Coast Guard cutters.

For ships of special type, especially those in which the auxiliary equipment plays an important part, the decision as to the most efficient type of propelling motor to use from the standpoint of over-all efficiency depends upon a study of the specific duty of the ship with relation to its given trade route and operating conditions.

Fig. 44 shows a simplified connection diagram of the main and field circuits of a twin-screw ship with a wound-rotor induction motor. Fig. 43 shows diagram of controls. The motor has external resistance for starting and for operation of the propeller at reduced speed, as during maneuvering. It can do this without reducing the speed of the main turbine-generator below ⅔ normal speed. Each of the dual-drive sets shown consists of an AC machine, a DC generator and a small turbine, all connected in tandem. When the ship is operating at sea, with the main turbine-generator running at ⅔ speed or over, the AC machine drives the DC generator, and the turbine is allowed to idle. Certain auxiliaries are driven by AC motors, and these derive their power directly from the main circuits. The direct current for excitation and for the few DC auxiliary motors is furnished by the DC generator of the dual-drive set.

When the main generators are being operated at below ⅔ speed and when the ship is in port, the small turbine of the dual-drive set assumes the load, furnishing power for the DC auxiliaries from the attached DC generator, and the AC power from the AC machine, which now acts as a generator. The following apply to the numbers shown on Fig. 44.

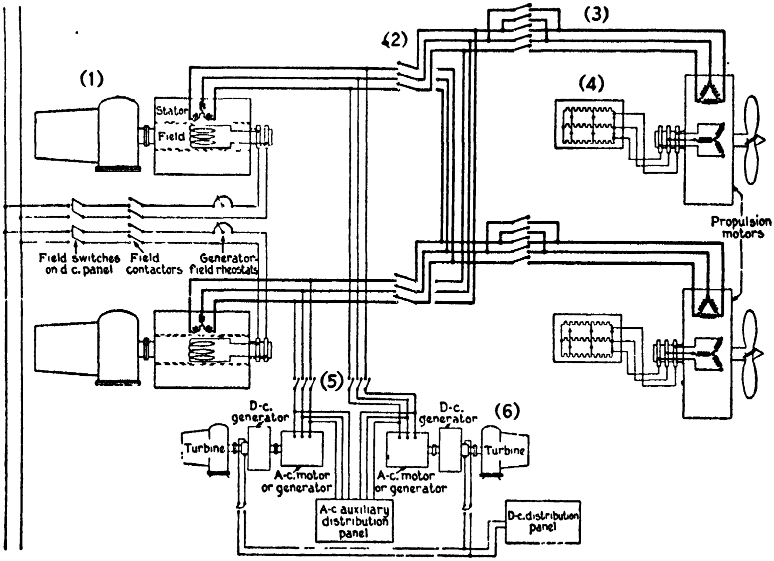


FIG. 44. Electric propulsion with wound rotor induction motors.

1) The 2 main turbine-generator sets which furnish power to the propulsion motors. When operating at not less than ⅔ full speed, these main sets also furnish auxiliary AC power.

2) Generator cutout switches for connecting each main generator to its propulsion motor or for connecting one generator to drive both propulsion motors.

3) Reverse contactors, operated by reverse levers at the control panel, serve to determine the direction of rotation of propulsion motors for ahead or astern propulsion.

4) Motor-rotor resistance for use during starting operations and for reducing motor speed below ⅔ full speed.

5) Under normal conditions one of these contactor groups is closed and the

main generator furnishes AC power to the motor of the dual-drive set, which in turn furnishes auxiliary DC power.

**6)** Dual-drive sets. When the speed of the main set goes below about ⅔ full speed, the speed of the dual-drive set is proportionally reduced, and its turbine governor moves to a position that causes switches at **5)** to open and at the same time admits steam to the turbine to drive the set. The AC machine then operates as a generator to furnish auxiliary AC power, and the DC machine continues to furnish auxiliary DC power.

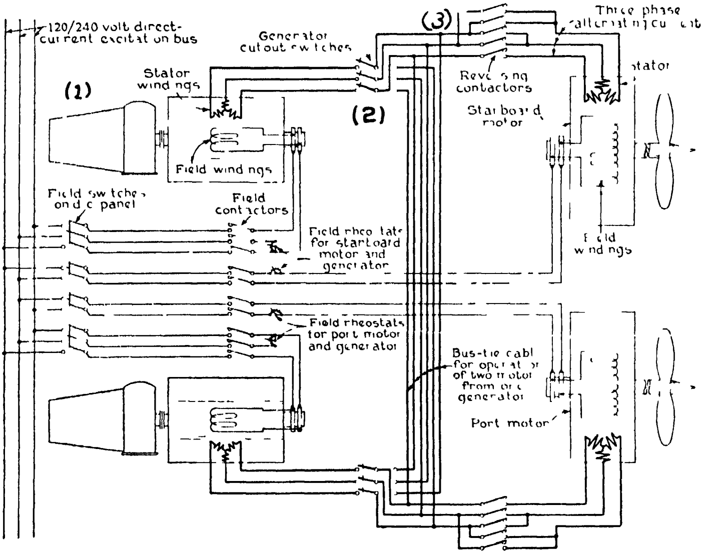

120/240 volt direct-current excitation bus
Generator cutout switches
(3)
Three phase alternating current
Stator windings
(1)
(2)
Reversing contactors
Stator
Starboard motor
Field windings
Field switches on d c panel
Field contactors
Field rheostats for starboard motor and generator
Field windings
Field rheostats for port motor and generator
Bus-tie cable for operation of two motors from one generator
Port motor

Fig. 45. Electric propulsion with synchronous motors.

Fig. 45 shows a simplified and typical connection diagram of the main and field circuits of a twin-screw ship with synchronous propelling motors, and Fig. 46 is a diagram showing controls.

The following paragraphs apply to the numbers shown on Fig. 45.

**1)** The 2 main turbine-generator sets which furnish power to the propulsion motors. When operating at not less than ⅔ full speed, these main sets also furnish auxiliary AC power.

**2)** Generator cutout switches for connecting each main generator to its propulsion motor or for connecting one generator to drive both propulsion motors.

**3)** Reverse contactors, operated by reverse levers at the control panel, serve to determine the direction of rotation of propulsion motors of ahead or astern propulsion.

## GENERAL ELECTRIC TURBO-GENERATOR EQUIPMENT

**Operation instructions,** one generator or two generators in parallel. The instructions pertain to equipment just mentioned.

### ONE-GENERATOR OPERATION

When operation is to take place with one main generator driving both propulsion motors, the field switch of the idle generator should be opened and the generator cut-out switches should be placed in the proper positions. The turbine to be used should be running with its governor set at the maneuvering-speed position.

**To start ahead.** Operate as described for 2-generator operation except that governor lever of idle generator is not used.

**To stop.** Operate as described for 2-generator operation.

**To reverse.** Operate as described for 2-generator operation.

**To stop one motor.**

1) Move governor lever to maneuvering-speed position.

2) Place field levers of both machines in "Off" position.

3) After a delay of about 2 seconds place the reverse lever of the motor to be stopped in the "Off" position.

4) Move both field levers to the "Run" position.

5) Move governor lever to obtain desired speed.

**To reverse one motor.**

1) Move governor lever to maneuvering-speed position and both field levers to the "Off" position.

2) After a delay of about 2 seconds move reverse lever of motor to be reversed to the "Astern" position.

3) Move field levers back to "Run" position as described under "To Start Ahead."

4) Move governor lever to obtain desired motor speed.

### TWO-GENERATOR OPERATION

When propulsion is to take place with both main generators and both propulsion motors operating, the two turbines should be running with their governors set at the maneuvering-speed position. The generator field switches should be closed and the generator cutout switches should be closed in the "Up" position.

**To start ahead.**

1) Pull the 2 reverse levers to the "Ahead" position.

2) Pull the 2 field levers to position 1. This places the generator fields across the 240-volt excitation bus, and leaves the motor fields open so that

## Upkeep of Electric Apparatus

The main essentials in the upkeep of electric apparatus are cleanliness, good contact, and tightness of connections The contact members of all types of disconnecting or interrupting devices must be kept clean and bright to insure maximum operating efficiency

General instructions for inspecting control equipment

Inspect every three months and adjust if necessary

a Remove arc chutes and inspect contact tips, smooth the tips with a file where necessary, and lightly grease all contacts Tips worn beyond a given allowance should be renewed

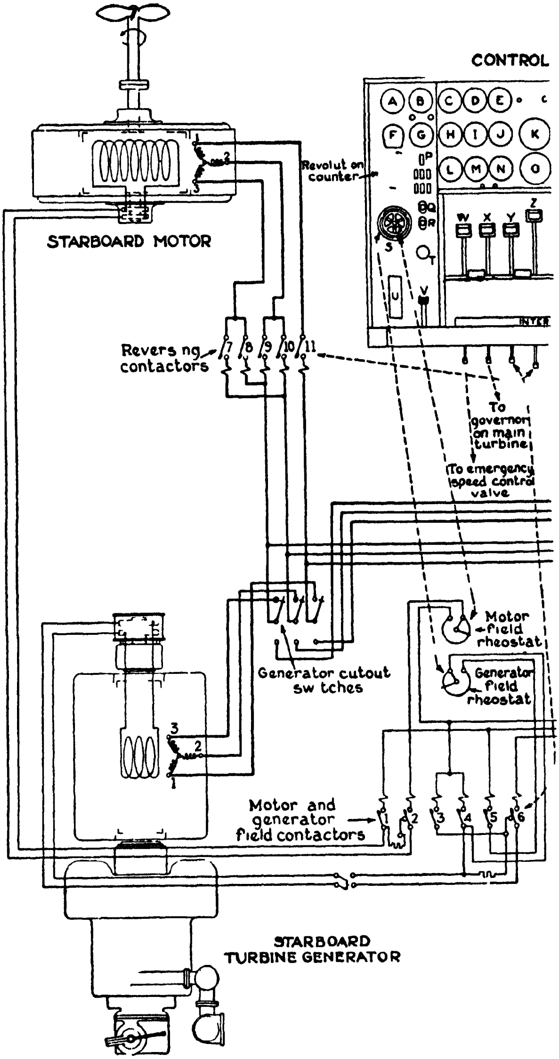


FIG 46A Electric propulsion with synchronous motors, starboard side, showing controls

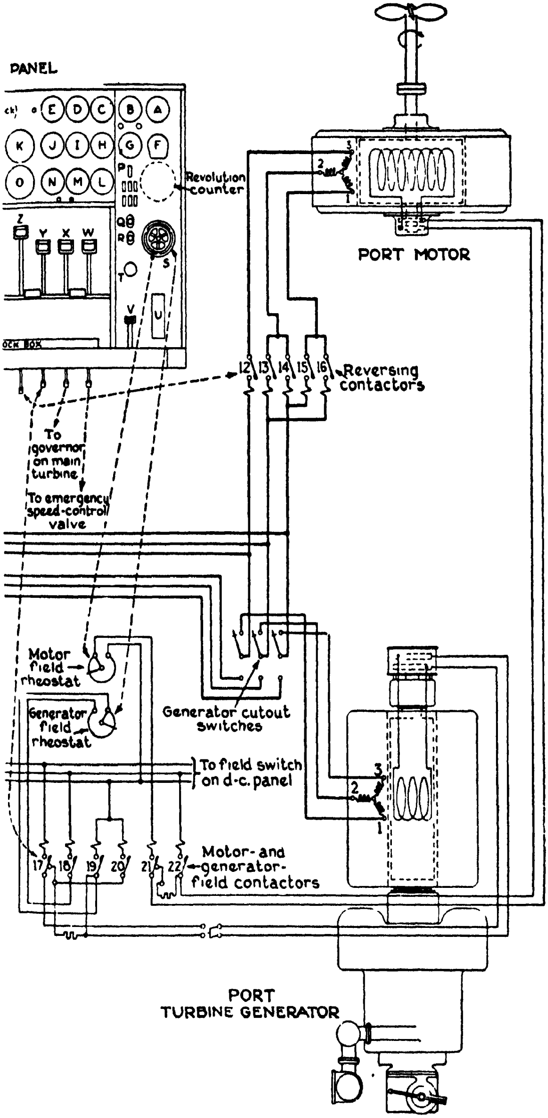


FIG. 46B. Same as 46A, port side.

b. Adjust shunts to permit free movement of attached parts.

c. Tighten all bolts, nuts, and screws if necessary.

d. Operate moving parts by hand to see that they move freely without excessive play.

e. Inspect arc chutes, barriers, and insulated parts and clean them.

f. Inspect contacts of pull switches.

g. Inspect rheostats of main generator, main motor, and blower motor. See that contactor surfaces are bright and connections tight.

h. Oil all cams, interlocks, rollers, lever bearings, etc.

the motors start up as induction machines; at this time the needle of each motor line ammeter will be at the top of the scale, but when the motors attain a constant speed the needles will drop back immediately to almost zero. Then,

3) Pull the 2 field levers to position 2. This closes the field circuits to the motors, which now pull into synchronism with the generators.

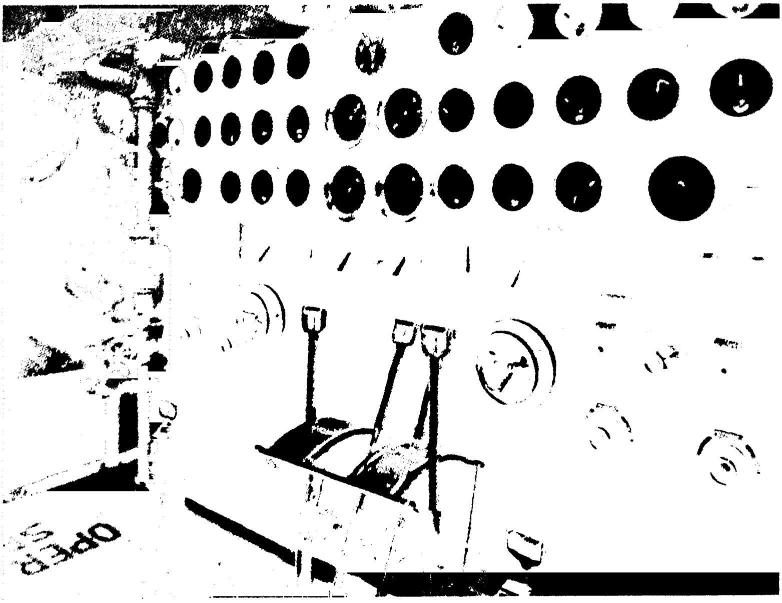


FIG. 47. Main propulsion control panel

4) Pull the 2 field levers to the "Run" position, and then move the governor levers to obtain the desired speed of the propulsion motors.

**To stop.**

1) Move governor levers to maneuvering-speed position.

2) Place field levers in the "Off" position.

3) After a delay of about 2 seconds place reverse levers in the "Stop" position.

**To change from ahead to astern propulsion.**

1) Move governor levers to maneuvering-speed position.

2) Place field levers in the "Off" position.

3) After a delay of about 2 seconds place reverse levers in the "Astern" position.

4) Move field levers back to the "Run" position as described under "To Start Ahead."

5) Move governor levers to obtain desired motor speed.

Fig. 47 is a typical control panel used with the equipment just reviewed.

## ALTERNATING-CURRENT MOTORS FOR PROPULSION

Two types of alternating-current motors are used for propulsion purposes in merchant-ship applications: namely, the wound-rotor induction motor (also called the "slip-ring" type) and the synchronous motor with squirrel-cage starting winding.

The wound-rotor induction motor has been applied to many ships of special types, among them the self-unloading, bulk-freight carriers and car ferries. Double-ended ferry boats have induction motors using the double squirrel-cage type of winding.

The synchronous motor with squirrel-cage starting winding has been applied to all late and modern passenger and combination passenger-cargo ships.

The stators of the motors of both types are the same, the difference being in electrical characteristics and the construction of the rotors. In the description which follows, the stators will therefore be dealt with collectively and the rotors separately.

The stator consists of the frame, the core and the armature coils.

The stator frame is designed to form a very rigid structure for resisting any tendency to deflect under strains due either to the weight of the punchings and windings or to magnetic pull. Ribs are fastened to the inside of the frame, and on these are assembled the laminated punchings which form the core. Spaces between the punchings are provided at given intervals for the passage of ventilating air.

The stator or armature coils, which are form-wound and specially insulated against moisture, are inserted in the slots in the face of the core and held in place by suitable wedges. The terminals of the windings are connected to heavily insulated end rings, to which are attached the connecting power leads. The outer frame is covered with metal lagging, which serves as a housing for directing the flow of air to the suction inlet of the ventilating fans and thence outward to the exhaust ducts or, if the motor is provided with a closed system of ventilation, to the air coolers. The propelling motors, because of their relatively low speed, require an external ventilating system. When the open system of ventilation is used, screened openings are provided in the end shields for the admittance of the air which is drawn from the engine room. When the closed system of ventilation with air-cooler arrangement is used, the motors are entirely cased in.

Temperature detectors are located at various points in the motor stator and are connected through a connection board located at the side of the motor to the stator temperature meter located on the control panel. The readings of the various detectors are obtained by plugging in at the temperature testing panel located on the control panel.

Heaters are located within the motors to prevent condensation or accumulation of moisture on the windings during periods of idleness. Fire extinguishers are also provided.

The end shields, which usually carry the bearing housings, are of very heavy construction and firmly bolted to the stator frame. The bearing housings and also the end shields are generally split at the horizontal joint for ease in assembly and disassembly.

**Rotor construction of wound-rotor induction motor.** The rotor of the wound-rotor induction motor consists of the spider frame, the core, the secondary winding and the collector rings.

The spider frame is heavily constructed to impart the turning effort to the propeller shaft, and may be of either the cast or fabricated type. The frame is provided with axial bars of the slotted type on its outer periphery for the reception of the core. The core is made up of annealed and enameled segments of thin sheer punchings, and slots are provided for the reception of the windings. The windings are form-wound, thoroughly insulated against moisture, and held in the slots by suitable wedges. The terminals of the 3-phase windings are connected to the collector rings, which are mounted on the shaft inside the motor housing.

The secondary current from the collector rings is taken up by a series of brushes held against them by spring pressure. From the brush holders the current is carried by bus-bar connections to the side of the motor where the cables are attached which lead from the resistor elements.

The resistors are generally of the water-cooled type and they are provided with short-circuiting contactors, which permit variation of the resistance in several increments. The contactors are remotely controlled from the operating panel, and this function together with the opening and closing of the generator-field contactors is generally combined under the operation of one lever, the field lever. The resistance is inserted into the secondary or rotor circuit only when starting up the motor or when operating the motor at a speed lower than that corresponding to the frequency, as when maneuvering. When running, as at sea, and when the motor speed is being controlled by the speed of the turbine-generator, the resistors are entirely short-circuited.

**Rotor construction of synchronous motor with squirrel-cage starting winding.** The rotor of a synchronous motor with squirrel-cage starting winding consists of the shaft, spider and rim, pole pieces, and collector rings. The spider and rim are of either cast or fabricated construction, but in either case the construction is heavy to impart the necessary turning force to the propeller shaft.

The pole pieces, which are bolted to the rim, are made up of laminated punchings and are pressed together hydraulically and held in place by through rivets. The field winding, which carries the direct-current excitation, is made up of form-wound insulated copper strip. The field coils are connected in series, and the terminals are attached to the collector rings on the shaft.

The squirrel-cage starting winding, which consists of metal bars with short-circuited ends, is placed in slots which are provided in the face of the pole pieces. This winding is inactive when the motor is operating at synchronous speed, because under these conditions it ceases to cut magnetic lines of force upon which it depends for its magnetizing current. In starting, and before direct current is applied to the pole pieces, the speed of the revolving flux in the stator is greater than that of the rotor, and the winding therefore acts on the induction-motor principle.

## TURBO-ELECTRIC PROPULSION INSTALLATION

The following is a description in part of the electrical propulsion equipment installed on the *S.S. President Coolidge,* and will serve as a guide to familiarize the reader with this type of machinery. The equipment of this ship was manufactured by the Westinghouse Co. and designed to operate on 3-phase AC, 4000 v., 1470 amps., at 133 r.p.m., at which speed the frequency was 44.3 cycles.

**General.** The vessel is the twin screw type, each propeller being driven by a revolving field salient pole synchronous type motor. Normally each propulsion motor is electrically connected to a turbo-generator through a suitable control equipment. Speed control is accomplished by throttling the turbine, but the propellers are reversed by interchanging 2 of the 3-phase leads connecting the motor primary. Thus the turbines and generators run continuously in the same direction, and the same torque and speed variations are available for going astern, or maneuvering, as for going ahead. In addition, the momentum of the relatively high speed turbine generators is available for use in quick reversing or stopping the vessel. The turbine is throttled to the ¼-speed position during reversing, but it always runs in the same direction; and it is not necessary to wait for the turbine speed to come down before the reverse power is applied. With each motor connected electrically to its corresponding generator, the speed of either propeller may be varied or reversed irrespective of the other.

The control is arranged so that one turbine generator may be electrically connected to both propulsion motors, but this condition does not allow independent speed variation of the propellers. This provision also removes the necessity of dragging a propeller in case of breakdown of the main turbines. The speed may be varied and either motor may be stopped or reversed independently of the other.

The electric drive employed on this installation gives ideal conditions for high efficiency in steam turbine propulsion: namely, a high speed turbine for the best turbine efficiency and a relatively low speed propeller for the best propeller efficiency. The speed ratio between the turbine and propulsion motor is the same as the ratio of the number of poles of the motor to the number of poles of the generator. In this case, the speed ratio is 20 to 1.

The electrical system employed is primarily a system of controlling and transmitting power, which has thoroughly proven itself in practice. It has special advantages in giving a large choice of speed ratios between the turbine and the propeller; permits flexible arrangement as to machinery location; is quiet in its performance, and gives ease of maneuvering ability.

Four auxiliary turbine generator sets are included to supply auxiliary power light and excitation. These generators are 3-wire and are arranged for 120–240 v. DC. One auxiliary generator connects regularly to the excitation circuit for the propulsion machinery. Normally, excitation for the propulsion generator is 120 v. DC, but 240 v. DC excitation is used when phasing in the propulsion motors.

The ratings and description of individual pieces of electrical machinery are given in the following pages.

**Propulsion motors rating.** A single motor has the following rating at 100% power factor:

| Ship's Power | Horsepower | Volts | Line Amperes | R p m. | Cycles |
|---|---|---|---|---|---|
| Maximum | 13250 | 4000 | 1470 | 133 | 44.3 |
| Normal | 11000 | 3650 | 1340 | 125 | 41.7 |
| Cruising | 8500 | 3220 | 1170 | 115 | 38.3 |

The fields are excited at 240 v. DC, full field current at maximum power being approximately 280 amps. The insulation is suitable for operation in an ambient temperature of 122° F. The allowable temperature rise for the stator, as measured by temperature indicating instrument, furnished on the propulsion control panel, is 122° F. The fields have no temperature indicating device, but field ammeters are provided and excess temperatures will not exist, provided the field current is kept at approximately 280 amps. Asbestos insulation is used on the field coils, and they are suitable for a temperature rise of 140° F. as determined by the resistance method.

**General features of construction.** Each motor is separately ventilated by means of a separately driven exhaust blower. Cooling air is drawn in through the bracket openings at both ends of the motor, passes through the coil ends and ventilating ducts provided in the core, into the space

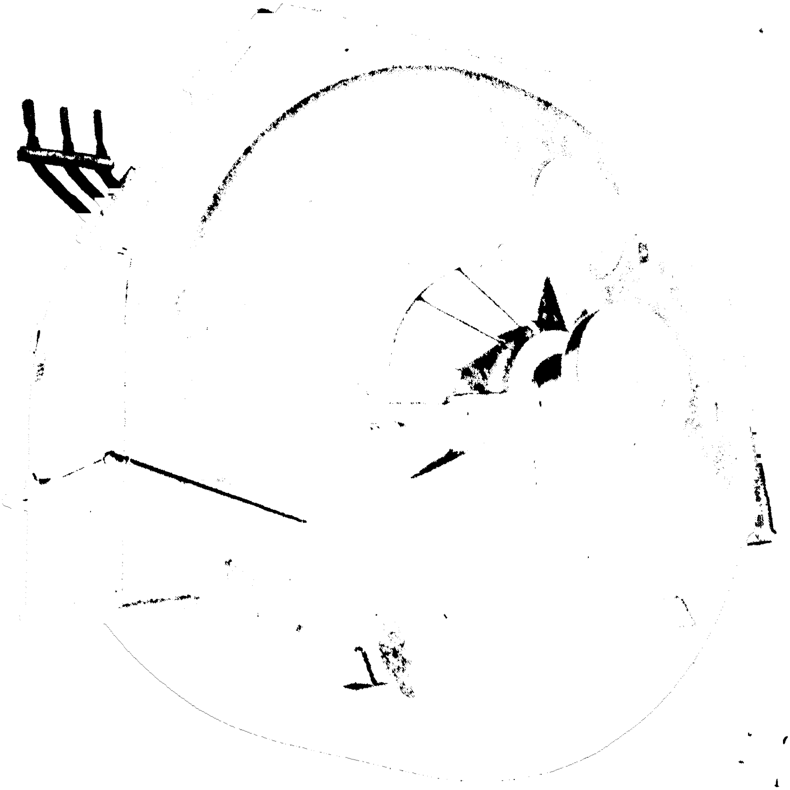


FIG. 48. Self-contained propulsion motor, looking at coupling end.

back of the core, and then goes out at the top of the motor through the blower and discharges through a duct to the deck. Ventilating air at 30,000 cu. ft. per min. is required for the maximum power rating of each motor.

The motors are of the self-contained, 2-bearing bracket type as shown by Fig. 48. The rotor is supported by 2 bearings, each bearing being carried by a steel bracket which fits into a rabbetted recess in the frame, to which it is bolted. The shafts have an integral flange fitted on the after end for coupling to the propeller shafts.

## MOTOR STATOR CONSTRUCTION

**Frame.** The stator frame is of the rigid box section type, welded from steel plates, with an opening at the top for discharging the ventilating air. The outside longitudinal edge of each foot is machined to form a guiding surface when the stator is moved to uncover the rotor for inspection or repairs.

**Stator core.** The stator core is built up of segmental steel laminations. The back portion of each segment has 2 punched projections, which fit approximately half-way round bolts that extend through the stator end plates. Segments form a complete circle of punchings, and through bolts clamp the laminations between the end plates. A row of vent spacers is provided approximately every 2 in. of core width in order to insure uniform cooling.

**Stator winding.** The stator winding consists of 360 coils of 4 turns each which are completely formed, molded and insulated before being placed in the slots. The insulation is applied and thoroughly treated with insulating varnish and baked before being placed into the slots. The coils are held in the slots by means of hard fiber wedges. The coil ends are securely lashed to an insulated steel ring, which in turn is secured to the frame by means of insulated brackets and bolts. The finished winding is treated a number of times with a high grade baking varnish after all connections are made. The main terminals are brought out through the frame on the inboard side.

**Bearings.** The bearings are the sleeve, oil ring type, having 2 rings per bearing, which supply sufficient oil to lubricate the journals at all times. Special features, such as roller guides and clearances, are provided which permit operation with the bearings permanently inclined at 15° either laterally or longitudinally. The bearing linings are babbitt, cast in gray iron shells. They are split on the horizontal centerline. (The oil rings are also split, which permits removal of the ring by simply removing the top half of the bearing housing and bearing.) In addition to ring oiling, the bearings are arranged for forced feed lubrication from the ship's gravity oiling system. Thermometers and illuminated sight flow indicators, for separate mounting in the oil piping system are a part of this equipment. The forward and after bearings are identical and interchangeable as units. However, bearing halves are not interchangeable.

**Bearing housings.** The bearing housings are split on the horizontal centerline into two halves, and are so arranged that the bearings and housings may be dismantled without removing the brackets. The joint between the two bearing housing halves is leak-proof. The overflow oil pipe is arranged to maintain automatically the proper oil level in the bearing housing. The bearings are designed for an oil flow of approximately 1½ gal. of oil per minute per bearing from the ship's gravity system. The oil inlet pipe to each bearing is ⅜-in. iron pipe size, and is suitable for oil pressures of from 6 to 12 lb. per sq. in. If flooding of the bearing should occur, due to improper pressure, it will be necessary to throttle the feed line or install suitable restricting orifices.

## MOTOR ROTOR CONSTRUCTION

**Spider.** The rotor spider consists of a rolled steel rim with 8 pairs of structural steel arms and a steel hub.

**Rim.** The rim is made of two circular formed rings, which are placed side by side and welded at proper intervals around the circumference and welded at the ends.

**Field Poles.** The field poles are built up of sheet steel punchings which are securely riveted together. Slots are provided in the pole head for the bars which constitute the squirrel-cage maneuvering winding. Each pole is held upon the rim by means of tap bolts which screw directly into the pole body.

**Field coils.** The field coils are made of copper strap, wound on edge. Asbestos insulation which has been soaked previously in shellac is placed between adjacent turns. These strips are placed between the turns, heat and pressure are applied until all of the solvents are squeezed out or driven off. In the finished state, the outer edges of the copper strap are practically bare, allowing the heat to be effectively dissipated from the exposed edges. A built up mica and asbestos cell is used between the pole and the field coil.

**Collector.** The collector consists of two brass alloy rings which are supported on a cast steel hub. A mica insulation cylinder is used between the hub and the rings. The collector hub fits into a recess of the spider hub, free of the shaft, and is held in place by tap bolts.

**Brush rigging.** The brush rigging is supported from the bearing housing. Six 1¾ × ⅝ × 2½-in. metallized brushes per slip ring are used. Individual brushes are held against the rings by means of spring pressure, and the brush holder is arranged so that the brush pressure may be adjusted for the best operating condition. The proper brush pressure is approximately 2½ lb. per sq. in. of brush area in contact with the ring.

**Shaft.** The shaft is made from a solid steel forging, the characteristics of which meet the American Bureau of Shipping requirements. The coupling half is an integral part of the forging. The collector end of the shaft is bored part way to permit the insertion of a steel bar, which provides a purchase for the rotor support when sliding the stator forward.

**Motor fire protection.** Inside each motor bracket is a circular brass pipe with a number of small drilled holes, arranged in such a way that water can be sprayed on the stator end windings in case it should ever be necessary. In case of fire, open the field, return the direction lever to the "off" position and stop the blowers. If the fire is of a minor nature, it may be extinguished by spraying fire extinguisher directly on the burning portion. If a fire actually exists and cannot be fought locally, the sprinkler system to the motor having the fire should be opened.

Once water is sprayed into the windings, power must not be re-applied until after the windings have been thoroughly dried and withstood the proper dielectric test.

Strict precautions should be taken against members of the crew inadvertently admitting water to the sprinkling system. Turn water into this system only as a last resort. (See section under Generators entitled "Generator fire protection" for means of preventing valves from being opened by accident.)

**Heaters.** Electric heaters are installed inside the motor to keep moisture from collecting on the windings during idle or lay-up periods. The total heater rating for one motor is 4 kw., 230 v. Two kw. capacity is distributed in each end of the motor.

**Ventilation.** Each motor is separately ventilated by means of a motor driven blower. Air is drawn in through the coils and ventilating spaces through the propeller type blower and is discharged through a duct to the deck. It is customary and necessary that the air discharge duct from the motors be arranged in such a manner as to prevent water from entering the motors through the ventilating system.

Each propulsion motor requires 30,000 cu. ft./min. ventilating air at 1¾ in. of water static pressure. The blowers supplied with this equipment are each rated 31,500 cu. ft./min. at 3½ in. of water static pressure. The additional quantity of air over that required for each propulsion motor allows 1500 cu. ft./min. of air for cooling the field resistors of each propulsion motor and generator. These resistors are of the hooded type, having ventilating pipes leading directly into the suction side of the motor ventilating ducts. The static pressure over 1¾ in. of water drop through each propulsion motor allows for the drop in the discharge duct. The capacity of each blower is sufficient to give 42,000 cu. ft./min. at 1½ in. of water static pressure when one blower is used to furnish ventilating air to both propulsion motors. Individual ventilating systems of each propulsion motor are interconnected to permit single blower operation, but this condition necessitates reduced power operation.

The power which the motors will deliver under this condition can be determined by trial, observing the motor temperatures and taking care that the rated values are not exceeded.

**Blower motor and control.** A 230-v., DC, vertical type motor drives each blower. Each motor has a maximum rating of 25 HP at 2000 r.p.m. A speed adjustment of 1470/2000 r.p.m. by shunt field control is available.

A magnetic type starter is supplied for each motor. Starting push buttons and speed adjusting rheostats are mounted on the propulsion control panels. A line ammeter for each blower motor is also supplied, which provides a means of indicating at what load the blowers are operating.

## PROPULSION GENERATORS

**Rating.** A single generator has the following rating at 100% power factor:

| Ship's Power | Kilowatts | Volts | Line Amperes | R.p m. | Cycles |
|---|---|---|---|---|---|
| Maximum | 10200 | 4000 | 1470 | 2660 | 44.3 |
| Normal | 8480 | 3650 | 1340 | 2500 | 41.7 |
| Cruising | 6520 | 3220 | 1170 | 2300 | 38.3 |

The fields are normally excited at 120 v. DC, and full field current at maximum rated power is approximately 525 amps.

The generator cooling air is water cooled, the cooler capacity being sufficient to give 104° F. air when leaving the cooler. The allowable temperature rise for the stator, as measured by the temperature indicator supplied on the control panel, is 140° F.

**General features of construction.** The generators are of the turbine type, being directly connected to the steam turbine shaft. A force-lubricated pedestal bearing is used on the collector ring end, while the rotor weight on the coupling end is supported by the exhaust end turbine bearing.

The generators are of the self-ventilated type, having air circulating fans mounted on each end of the rotor. The circulating air system is a closed circuit, the same air being used over and over again. The air passes through the generator, absorbing the heat incident to the generator losses, and then is directed through a radiator type cooler, which is located underneath the generator, and which has sufficient capacity to reduce the air temperature to 104° F. when 28,000 cu. ft./min. is flowing in a single generator and when full rating is being delivered.

The rotors are of rigid construction and have the collector rings outside the pedestal bearing designed to lessen critical vibrations in the operating speed range.

In general, the construction features of AC motors and generators are much the same, so in the main propulsion generators are built up along the same lines as propulsion motors. (See description of propulsion motors.)

**Turning gear.** The turbine turning gear is mounted on the collector end of the turbo-generator shaft. The turning gear consists of a ratchet wheel with pawl and lever attachments, giving the necessary mechanical advantage to jack the turbo-generator over very slowly by hand. Ordinarily, the ratchet wheel and pawl and lever mechanisms will be stored, but when it is desired to jack over the turbine it is necessary to remove the speed indicating magneto and small cover plate (secured by three countersunk screws) and bolt the ratchet wheel in place. (Note that it is not necessary to remove the brush rigging cover to attach this jacking gear.) Operators should never leave this wheel bolted to the shaft when the turbine is to be turned over under its own power.

**Lead location.** Four armature leads are brought out of the winding, the fourth lead being the neutral point. Only three leads are brought out through the ventilating casing, and these are located at the bottom of the generator on the collector end.

This generator is **Y** or star connected.

**Temperature coils.** Nine 10-ohm resistance coils are provided, and so located in the armature winding as to indicate as closely as possible the highest temperature obtained in operation. A terminal board, conveniently located, and necessary wiring between the board and the individual coils is provided. The dial selector switch and the measuring instruments are mounted on the main control board.

**Generator fire protection.** A turbine generator may be seriously damaged by fires where no means are provided for extinguishing them. The large volume of cooling air passing over the stator and windings will tend to spread very rapidly any fire started in the end windings. If the fire can be controlled within a short time after it starts, the damaged section of the windings may be limited to a few coils. The water may do some damage to the coil insulation but the fire is stopped before more serious damage is done.

If the machine is actually on fire, cut off the power to the turbine, open the generator field, move the direction level to the "off" position and turn on the sprinkler system (to the machine on fire), as the air passing through the machine will aggravate the trouble greatly.

The operator must be certain a fire exists before opening a sprinkler valve, to prevent a generator being made inoperative by a false alarm.

As a precaution to prevent the water line from being inadvertently opened to the sprinkler system, sometimes the valves are put within glass cases, which must be broken before the valve wheels can be reached. Another method is to have a detachable handle which is kept inside a glass case, or some other designated place in charge of the watch engineer. As it is very important to keep water out of the windings under normal operating conditions, sometimes two valves in series are installed in the pipe line leading to the generator sprinklers. In such installations, a leak-off pipe is installed between the valves to drain out any water that may get past the first valve. Another method of protection is not to have the sprinkler system directly connected to the water piping outside the generator, but to arrange a hose which can be quickly snapped on the water supply line. Such an arrangement would prevent anyone accidentally flooding the generator by opening the wrong valve, and would force some hesitancy in turning on the water in case of false alarm.

The sprinklers installed in these generators consist of two semi-circular brass pipes having a number of small holes drilled in the side of the pipe next to the ends of the armature coils. These pipes are mounted on the inner end bells and are arranged for connecting to the water line near the base of the end bells.

**Heaters.** Electric heaters are installed underneath the armature end windings to prevent moisture from collecting during idle periods. The total heater capacity of one generator is 3 kw., two 750-watt heaters being installed at each end of the machine. The supply voltage for the electric heaters is 230 v. DC, and the heater leads are brought to a terminal box located on the turbine and inboard side of the generators.

**Ventilation.** These generators utilize the radial type of ventilation. Ventilating air is drawn through the double enclosing end bells, passing through the single entrance fans, located on each end of the rotor, into the inner end bells and chambers around the armature end windings, where the high velocity air is converted into relatively low velocity and high pressure; then into the air gap between the rotor and stator, where the air paths branch off radially between the lamination packs into the enclosed spaces back of the armature core. From the space back of the armature core, the air, which has gathered the heat of the windings and laminations, discharges through an outlet in the bottom of the generator frame casing into the radiator type cooler, where it is reduced in temperature and begins to repeat its former cooling path.

The air passage described in the previous paragraph is over the periphery of the rotor and through the armature core. A second air passage begins underneath the steel retaining ring end plates of the rotor, passing underneath the end turns of the field windings into the ventilating slots, beneath the axial portions of the field winding, finally discharging into the air gap; thence through the ventilating ducts between the stator lamination packs, finally discharging into the cooler as in the previous case. The flow of air through the rotor is induced by the 1 in. diameter holes previously described in this section under "Rotor construction."

Thus it will be seen that ample air circulation has been provided to the innermost imbedded parts where hot spots would normally be expected to exist, and even temperature distribution is obtained.

Each generator has an opening provided at the top of the air casing for emergency ventilation in case the air coolers become inoperative. This opening allows air to discharge directly into the generator room when the solid cover is removed. Underneath the solid cover, a screen cover is welded in place to prevent foreign matter from falling into the generators while the solid cover is detached. This is only a temporary expedient, to permit reduced power operation until the air coolers can be repaired.

Approximately 28,000 cu. ft. of air per min. is required to cool each generator when operating under normal load. The capacity of the fans on the rotor is sufficient to circulate the required volume of air through the external radiator type coolers, supplied with this machinery. A cooler having 2 sections is supplied for each generator.

**Coolers.** An air cooler is installed in the cooling system of each generator. They are of the "U-fin" type. The tubes are made of Admiralty metal, are built in 2 sections each and are arranged for 4 passes of the cooling water. When a generator is operating under normal full load, the amount of cooling water is 14,400 gals. per hr. at 85° F. Under these conditions, the water pressure drop through the cooler will be approximately 4½ ft. For normal full load, the other conditions of the cooler will be about as follows:

| | |
|---|---|
| Air pressure drop through cooler (inches of water) | 0.9 |
| Heat loss in kw. | 353 |
| Heat loss in B.t.u. per hr. | 1,210,000 |
| Air temperature deg. F. entering cooler | 146.6 |
| Air temperature deg. F. leaving cooler | 104 |
| Raw salt water, quantity in lb. per hr. | 120,000 |
| Raw salt water, quantity in gal. per min. | 234 |
| Raw salt water, deg. F. entering cooler | 85 |
| Raw salt water, deg. F. leaving cooler | 95.1 |

## PROPULSION CONTROL

**General.** The propulsion control serves to transmit the power generated in the steam turbine and generators to the 2 propelling motors. Means are provided to regulate this power and the propeller speed and to drive the 2 propulsion motors individually from their respective generators or in parallel from either the port or the starboard generator.

The layout of the control is such as to insure simplicity of operation in conjunction with maximum reliability. All operation is individual by means of lever-operated cam switches, and proper sequence of operation is insured by mechanical interlocks of rugged proportions.

The whole control is subdivided in 2 compartments, a low voltage compartment with instrument panel containing the field and auxiliary switches, and a high voltage compartment with the reversing contactors, change-over switches and the instrument transformers. The high voltage compartment is totally enclosed and its door so interlocked that it cannot be opened unless the power is shut off.

The propulsion control consists of 2 symmetrical halves for the port and starboard drive and all explanations and descriptions given in the following pages, therefore, are to be applied to either side. Schematic diagram, Fig. 49, shows the interconnections between the generators and motors. A list of apparatus follows:

A) Low Voltage Compartment:

1) Operating desk with 7 operating levers, interlocks, bell cranks and operating rods for the operation of all switches.

2) Speed valves for controlling the speed of the 2 main turbines.

2) Emergency trips for the turbine governors.

2) Field rheostats for the main motors and generators.

1) Rheostat clutch for mechanically tying the 2 rheostats together.

2) Phase balance relays for the protection of the 2 main generators and motors.

2) Sets of instruments and instrument switches.
2) Field starting switches, Type XC–16–A.
1) Field change-over switch, Type XC–166–A.
2) Field circuit-breakers for main generators.
2) Field circuit-breakers for main motor.
2) Instrument switches for connecting precision instruments.
2) Ground detector indicating relays.
4) Calibrating rheostats for the speed indicators.
B) High Voltage Compartment:
2) Reversing switch groups, Type XC–15–A, for reversing of the main motors.
1) Change-over switch, Type XO–10, for operating the motors either individually or in parallel from either generator.
2) Sets of current transformers 2500/5 amps.
2) Sets of voltage transformers 4000/115 v., 44 cycles.
1) Door interlock magnet with 2 door switches.

## DESCRIPTION

**Reversing switch group, type XC–15–A.** These switch groups serve to reverse the direction of rotation of the main motor and consist of 5 cam-operated switch units **D1** to **D10** of diagram, Fig. 49 and shown on drawing, Fig. 50. A switch group frame of structural steel is provided for mounting these switches and includes the cam shaft with the 5 steel cams supported on ball bearings.

The switch has a rating of 2000 amps. at 4000 v. and is provided with magnetic blowout, which enables it to interrupt full power of the generator. Reference to Fig. 50 explains the switch mechanism in detail. It will be noted that the switch has 2 pairs of contacts, the arcing contacts **e** located in the magnetic blowout field and the main contact **g** which carry the current.

With the switch shown in the open position, it will be noticed that the rotation of the cam shaft **x** will move the fulcrum **a** upwards. The Micarta link **b** transmits this movement to the contact support **c** pivoted in fulcrum **d**. As the movement progresses the arcing contacts close and complete the circuit through the blowout coil **f**. After a while the main contacts **g** close and bridge the arcing contacts with the blowout coil, thereby establishing a direct current path of minimum resistance between the switch terminals **h** and **i**.

When opening the switch the main contacts **g** separate first and the current now flows through the blowout coils, thereby building up a powerful magnetic field. When the arcing contacts e finally open the arc is forced in the arc box j and is quenched by combined cooling and stretching action.

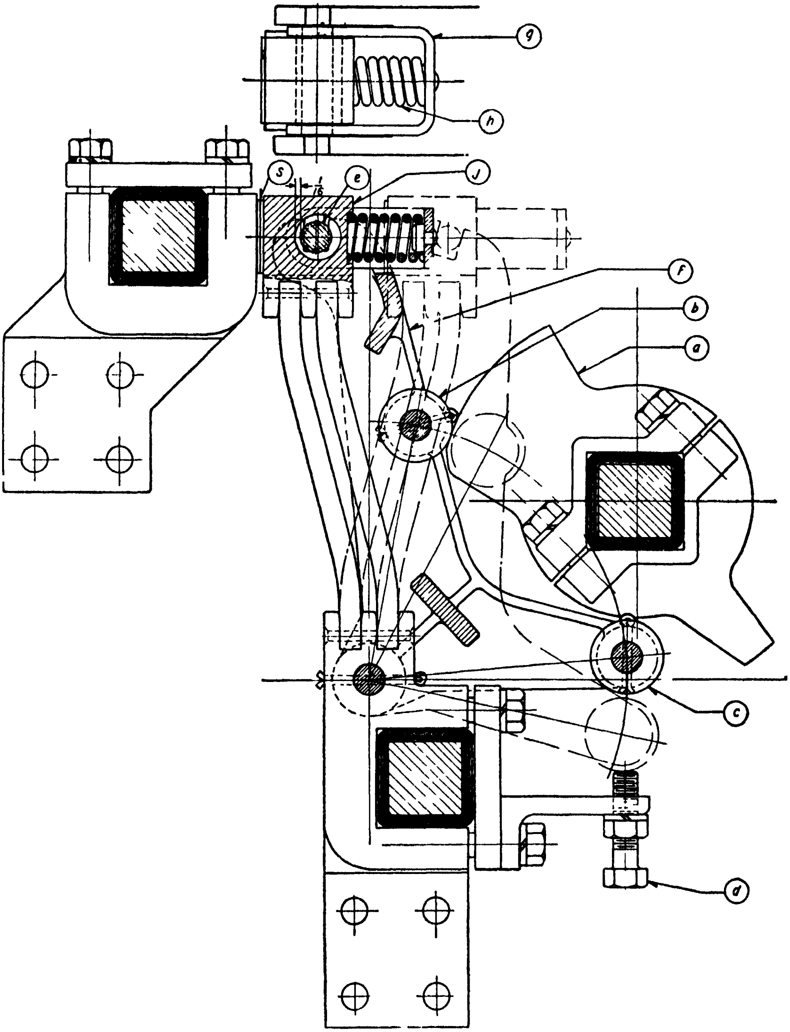


FIG. 50. Drawing of cam switch.

It is important that the main contacts separate about ⅜ to ½ in. before the arcing contacts open so as to make sure that the arc is transferred to the arcing contacts. Further reference to Fig. 50 shows that the main contacts **g** are provided with silver plates at their sealing point. It is very desirable that the point of contact separation is above the silver surfaces so as to keep the burning or pitting away from the sealing point. This is accomplished by a slight rolling action of the contact.

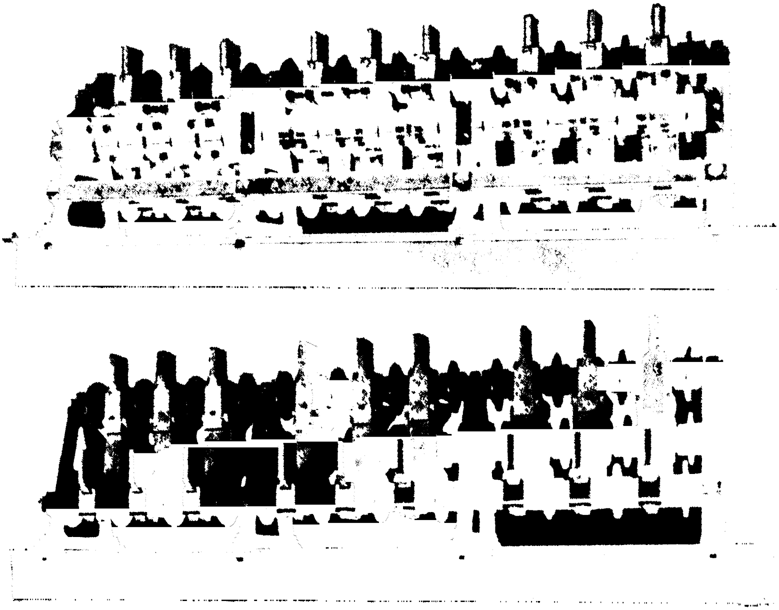


FIG. 51. Change-over switch. Top shows front view, bottom the rear view.

**Main change-over switch, type XO–10.** Fig. 49 gives reference to three 3-pole change-over switches marked **C12**, **C13** and **C14**. These switches serve to disconnect the generators from their motors and to connect the latter in parallel across either generator. All switches are combined in a single switch group shown in Fig. 51. A cross section of the group illustrating the switch mechanism is given in Fig. 52.

A special feature of this switch is the contact arrangement with the vertical silver contact surfaces s which practically eliminate all mainte-

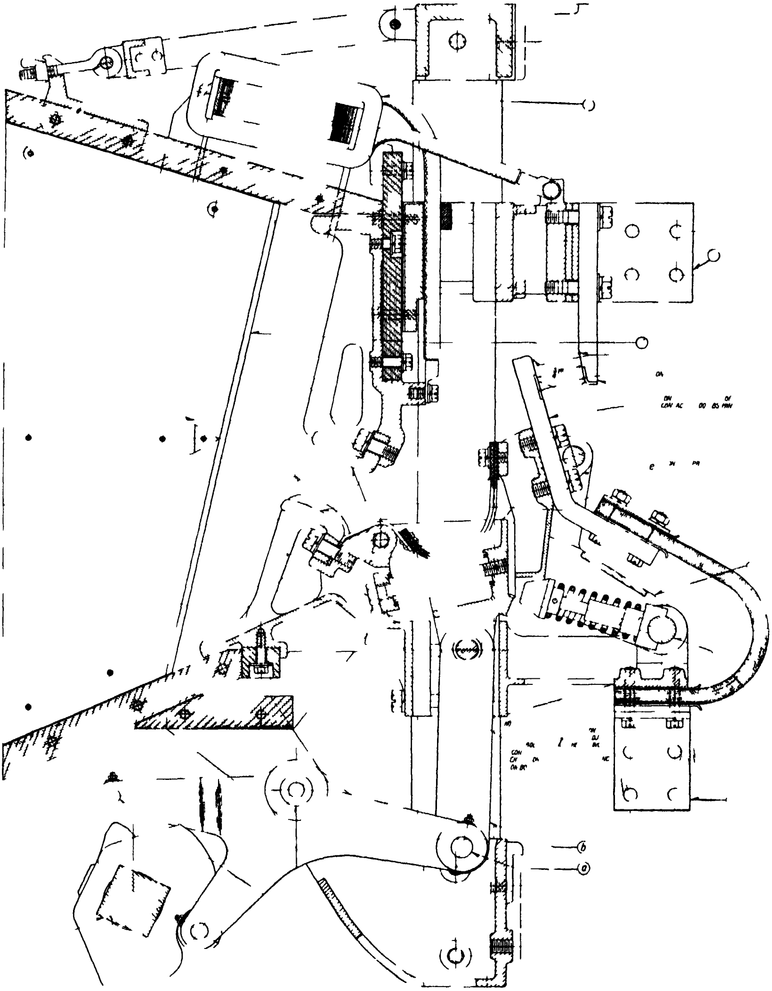


Fig 52 Cross section of switch shown in Fig 51

nance. A contact pressure of 70 pounds is sufficient to carry 2000 amps. continuously. Reference to Figs. 51 and 52 shows that the cams and contact blocks are mounted on well insulated steel bars with vertical partitions between the poles to prevent flash-over. The cam **a** rotates between two rollers **b** and **c** attached to the contact support **f** (Fig. 52). With the switch shown in the closed position a clockwise rotation of the cam shaft will force the roller **c** downwards and move the contact to the right until the contact is in the open position and the roller **c** is riding on the outside circle of the cam contour. The adjusting screw **d** serves to prevent play between the two rollers and the cam and should be adjusted so that there is about .005-in. clearance between roller **c** and the screw with the switch in the "off" position.

The movement of the casting **f** is transmitted to the contact block **i** through pin **e**, yoke **g** and spring **h**. In order to prevent jamming the mechanism it is important to have about 1/16-in. clearance between pin **e** and the wall of the hole in block **i** with the switch in the closed position as shown.

**Current and voltage transformers.** The current and voltage transformers are of the air insulated type and designed for 2500/5 amps. and 4000/115 v. respectively.

Special care is to be taken that the connections of the current transformer circuits are always tight and the circuits closed, because any loose connection will result in the tripping of the phase balance relay, which in turn will cause the shutdown of the corresponding main generator and motor.

**Door interlocks.** Access to the high-voltage compartment is only possible if both main generators are shut down. This interlock is obtained by means of a magnet with double winding 9–11 and 109–111 of Fig. 49. As long as one of the 2 generator fields is energized, the plunger of the interlock magnet will lock the door latch in the closed position so that the door cannot be opened.

In addition to this protection, 2 door interlock switches **15-N** and **115-N** are added to the door which will trip the field circuit-breakers and prevent starting of the motors as long as the door is open.

**Operating desk.** The operating desk is located in front of the instrument panel and controls the change-over, direction and field switches as well as the turbine speed valves, by means of 7 levers. The levers are made of cast steel and are provided with positive latch so as to lock them in the selected position. Reference to schematic diagram, Fig. 49, gives a plain view of the operating desk showing the various operating positions of the 7 levers.

Mechanical interlocks are provided between the operating levers so as to insure correct sequence of operation. These interlocks are arranged in a bedplate located at the rear of the operating desk. The interlock between 2 levers consists of a sliding key locking the bar by means of a V-shaped notch so that it cannot be moved until the interlock bar of the opposing operating lever is moved into such a position as to permit the lateral sliding of the key. A list of the mechanical interlocks follows:

1) The "change-over" lever cannot be moved unless both port and starboard direction levers are in the "off" position.

2) The direction levers cannot be moved unless the change-over lever is in one of the three operating positions.

3) The direction lever cannot be moved unless the corresponding "field" lever is in the "off" position.

4) The field lever cannot be moved unless the corresponding direction lever is in the "ahead," "astern" or "off" position.

5) None of the two direction levers can be moved if the change-over lever is in the "port" position and the port side field lever out of the "off" position.

6) None of the two direction levers can be moved if the change-over lever is in the "starboard" position and the starboard field lever is out of the "off" position.

7) The field lever cannot be moved unless the corresponding "speed" lever is at quarter speed or lower.

8) The speed lever cannot be moved unless the corresponding field lever is in the "off" or "run" position.

While the interlocks 1 to 8 are of a strictly mechanical nature and form part of the operating desk, there are 2 electrical interlocks added to the high voltage compartment as follows:

9) The door of the high voltage compartment must be closed before power can be applied. This is accomplished by providing the door with 2 door switches that trip the field circuit-breakers when the door is opened.

10) The door of the high voltage compartment cannot be opened unless the power is shut off. For this purpose the door latch is equipped with a locking magnet, with its 2 coils connected across the generator fields. As long as the generators are excited, the door latch stays locked.

The bedplate containing the interlocks is packed with grease, and should be inspected about every 2 to 3 years. The following are recommendations for assembling the interlock bars and sliding keys in the bedplate:

1) Place the speed, field and direction levers in the "off" position and change-over lever in the "port gen." position, so that the interlock bars a will be in the position shown on drawing, Fig. 53.

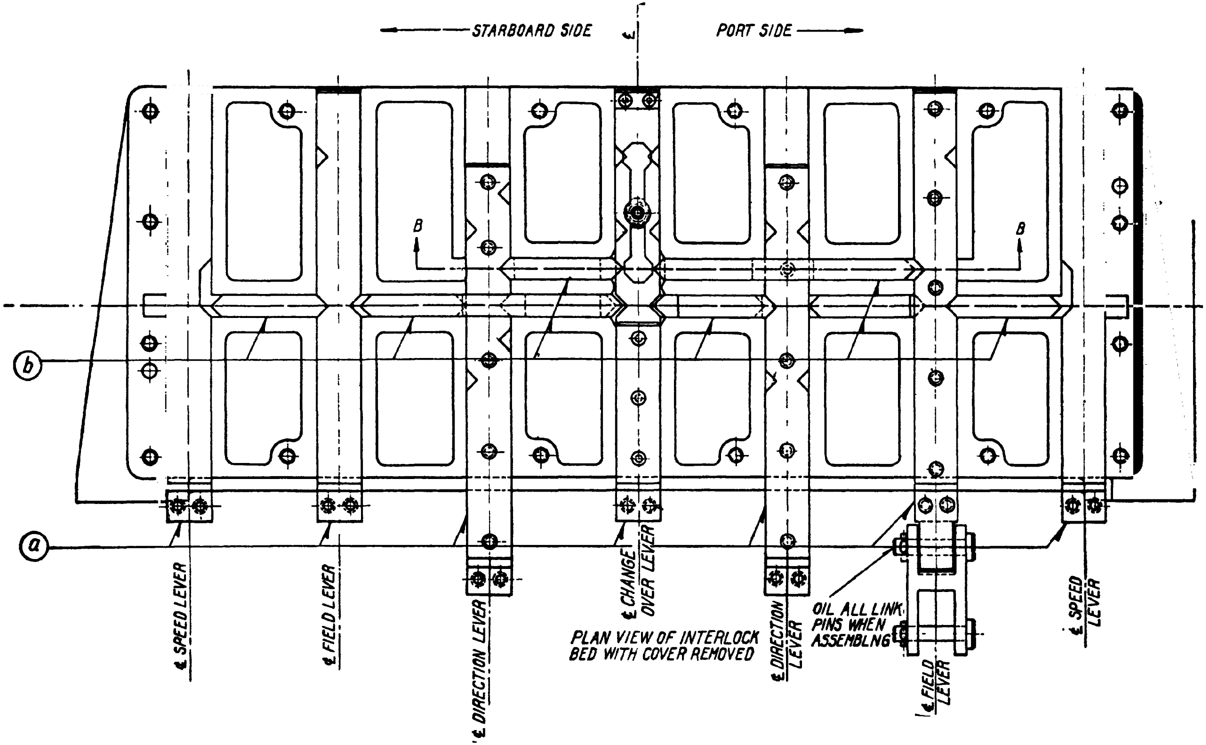


Fig. 53. Operating desk—interlock bed.

2) Then insert sliding keys **b** in the 2 grooves. Make sure that key item 1 is at its extreme right so that there will be no interference with pin 2 when assembling cover item 3.

3) Lubricate moving parts with light grease or vaseline and assemble cover carefully so as not to disturb setting of interlocks.

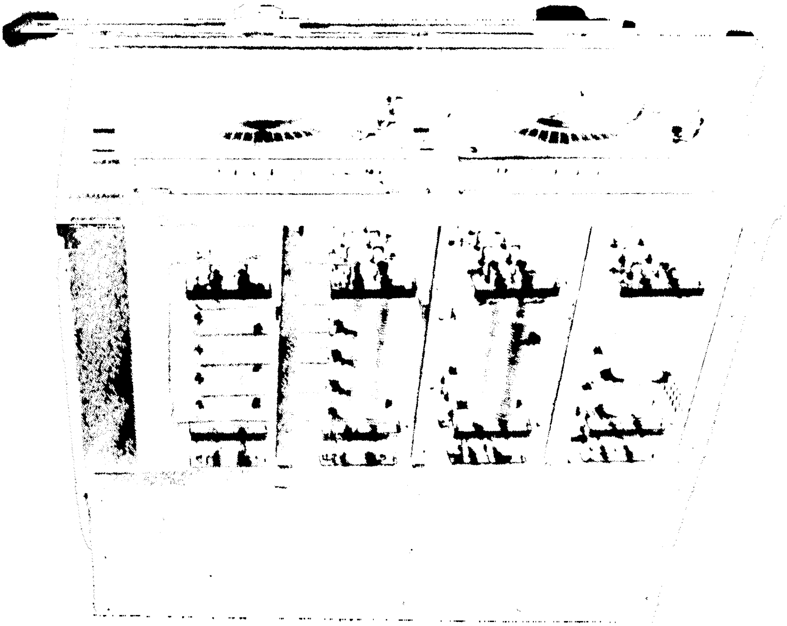


FIG 54. Field rheostat for main motor and generator. Cover plates partially removed.

4) Check performance of interlocks and see whether it satisfies the requirements enumerated in paragraphs 1 to 8.

All interlocks **a** and **b** are individually fitted in position so as to match the notches of the operating levers. It is recommended therefore to mark them before taking them out of the bedplate so as to insure a good fit when reassembling the interlocks

**Field rheostats.** The main motor and generator field rheostats serve to control the torque margin of the propelling motors. Two rheostat units illustrated in Fig. 54 and located separately below the propulsion control are provided, each one including the rheostats for the motor and generator of port and starboard respectively.

Reference to Fig. 54 shows that the motor and generator rheostats are operated from a single shaft, which in turn is connected to a handwheel through a 1 to 4 ratio bevel gear.

For individual generator operation the 2 rheostat handwheels of port and starboard side are operated individually and the clutch is in the open position. If on the other hand the 2 propelling motors are operated in parallel from either port or starboard generator, the 4 rheostats must be tied together so as to insure equal excitation of the four machines. In order to do this put rheostat clutch in the "in" position and turn handwheels in same direction until clutch engages. The rheostats may now be controlled from either one of the two handwheels.

It is important that the motors and generators be operated at unity power factor at any load or speed so as to reduce the losses and temperatures in the machine to a minimum. For this purpose the motor and generator rheostats are calibrated and permanently tied together so as to insure equal voltage and unity power factor at any speed and load. Thus the operator does not have to concern himself with power factor control at all. When operating the motors in parallel from a single generator resistance is inserted in the motor field to compensate for the reduced internal drop of the motors.

**Field starting switch, type XC–16–A.** This switch is operated from the field lever and is mounted at the bottom of the low voltage compartment. It serves to apply proper excitation to the generator motor, and consists of eight cam switch units provided with magnetic blowout capable of rupturing full field current. Suitable barriers are provided between the switches so as to confine the arc.

**Field change-over switch, type XC–166–A.** This switch is similar in design to the field starting switch.

It comprises 11 switch units without blowout, serves to disconnect and transfer the generator and motor fields. Assuming for instance, that the motors are running from the port generator, the starboard generator field is disconnected by opening switch **C10** while the starboard motor field is transferred to the port field starting switch. This simplifies the operation of the control considerably, in that for single generator operation only one field lever is used, thereby giving the additional advantage of simple mechanical interlocks.

Attention is called to the fact that the field change-over switch is operated from the change-over lever so that both the main and field circuits are transferred simultaneously with a single movement of the operating lever, thereby permitting changing over from individual generator operation to single generator operation with practically no loss of time and without any hazard involved of any kind.

A small interlock drum containing contact fingers is attached to the change-over switch so as to adjust the calibration of the stability indicator to the operating condition selected.

**Phase balance relay.** The generators and motors are protected by means of a phase balance relay which trips the field circuit-breakers when the unbalance in the 3 phases exceeds a certain percentage. It does not operate on a straight overload, such as occurs during maneuvering.

**Stability indicator.** Among the various instruments there are three meters that are of particular importance for the operation of the generator and motor. These are the two speed indicators and the stability indicator. There must always be sufficient torque margin available to prevent the motors from pulling out of step. This torque margin can readily be checked with the stability indicator which indicates the ratio between field excitation and load current in the 2 machines.

At normal current and voltage the meter is adjusted to read "normal stability." If the load increases on account of rise of speed, for instance, the current element overcomes the voltage element and the pointer is pulled towards the "low excitation" position: i.e., the torque margin is decreased below normal. This condition should be corrected by an increase of excitation so as to bring the pointer back to the middle position.

A decrease in speed should always be followed by a corresponding decrease in field current, in order to prevent a waste of energy and excessive heating in the field windings.

**Temperature indicator.** There are 2 temperature indicators provided for each port and starboard side. One instrument measures the temperature of the generator field by means of the resistance increase of the field winding itself. The internal wiring of this meter constitutes a circuit similar to a Thompson bridge and balances the current in the field against the drop across the rings. Two special pilot brushes **$PFG_1$–$PFG_2$** of Fig. 49 are provided for measuring the voltage drop to eliminate the error of variable main brush resistance.

The other temperature indicator measures the temperatures of the generator and motor stator and uses 10-ohm exploring coils imbedded between the coils inside the slots. A special temperature switch, with 9 points for the generator, 6 points for the motor and one test position, is provided to check the temperatures at the various points of the stator windings.

The control current for this temperature indicator is supplied by a small potential transformer and rectified by a copper oxide disc rectifier to 6 v. DC, both units being combined in a compact rectox unit. The primary of the potential transformer is connected across ½ of the preventive coil of the auxiliary generators, which corresponds to 85 v. at 40 cycles. A temperature indicator selector switch mounted on the auxiliary control panel behind the instrument panel is provided and permits taking power from whatever auxiliary generator is supplying excitation to the motor and generator.

The purpose of this separate power supply for the temperature indicator is to obtain a direct ground, **G6** of Fig. 49, which eliminates the danger of any static change of the control circuit due to the exploring coils imbedded in the high voltage winding.

The test coil has a constant resistance of 8.351 ohms, and is used to calibrate the temperature indicator before readings are taken. For this purpose move test switch to the "test" position. Then turn rheostat 21–81 located beside the temperature switch until the meter reads 0°. Any possible error due to a variable voltage supply is now eliminated, and accurate readings may be taken with any of the 15 exploring coils.

**Ground detector.** It is desirable that a close check be kept on the condition of the insulation of the high voltage circuit and that the voltage to ground of each phase be about equal. For this purpose, a special ground detector system is provided, comprising:

*a*) Three potential transformers 4000/115 v.
*b*) One triplex voltmeter with 3 separate voltmeters 0–5000 v.
*c*) One ground detector relay 35–40.
*d*) One pair of pilot lights "6–4."

The primaries of the potential transformer are grounded while the secondary windings are connected in open delta. Under normal conditions, i.e., with the insulation of the 3 phases in good condition, each meter of the 3 phases should indicate equal voltage to ground, and the resultant current through the relay coil 35–40 of diagram, Fig. 49, should be zero.

A change of the insulation of one phase is indicated by a corresponding decrease in the voltmeter deflection. This gives the operator a warning and may give enough time to provide suitable remedies before the insulation is seriously damaged.

If for some reason or another the operator fails to notice the slight change in insulation, the ground detector relay 35–40 with its contact 4–5 will operate when the voltage of the defective phase decreases about 1500 v. below the other phase voltages and lights 2 red signal lights.

Unless operating conditions impose the necessity of continued operation the faulty generator or motor should be shut down and the defective insulation located and repaired.

# VIII

# ELECTROMAGNETIC SLIP COUPLINGS

The electromagnetic slip coupling is a relatively new application of old electromagnetic induction principles, used for the transmission of power from one shaft to another—marine work, from the engines to gears or engine to shaft.

The following are extracts from a paper by Lory, Kilgore and Baudry presented before the Institute of Electrical Engineers, August, 1940:

**Introduction.** Electric couplings are devices for transmitting torque by means of electromagnetic forces in which there is no mechanical contact between the driving and driven members. Thus, they differ from electromagnetic clutches, which are only friction clutches in which an electromagnet is used to apply the pressure between the friction surfaces. Electric couplings are not new in principle, but their application on large scale has come only in the last few years. It is the purpose of this paper to review the principles of operation of electric couplings, describe their major application to geared Diesel engine ship propulsion, and discuss the engineering problems associated with this application.

Probably the idea of an electric coupling is nearly as old as the idea of an AC generator. There are a number of early United States patents from 1891 to 1906 describing at least the elements of the various types of electric couplings.

In 1934 and 1935, the authors made a study of the various types of couplings with the hope of applying them to marine drives. Since 1935 A.S.E.A. in Sweden have equipped a number of ships with electric couplings. A 3000-HP coupling was supplied by the Westinghouse Electric & Mfg. Company to the U. S. Navy and was quite thoroughly tested. At about the same time, two tankers were equipped with 750-HP couplings made by the Elliott Company. Within the past year, the United States Maritime Commission have purchased 116,000 shaft HP in electric couplings in 48 units to equip 20 vessels.

**Principles of operation.** The electric slip coupling is the type used on all of the large marine applications, and the discussion of the numerous other types will be reserved till the end of the paper. The slip type has poles excited by direct current on one rotating member, and an armature winding, usually of the squirrel cage type, on the other rotating member.

If it is necessary to vary the speed, the winding can be insulated and brought out to the slip rings, so that an external resistance can be connected in the circuit to vary the slip. Any relative motion or slip between the two members will induce currents in the armature winding which react with the flux to produce a torque tending to hold the two members close together in speed. This is similar in action to the usual induction motor, except that the rotating field is produced by a DC current in a rotating member instead of by polyphase current in a stator.

The coupling performs 4 functions in the drive as follows:

1) It acts as a torsionally flexible member between the engine and the gear, eliminating all shocks and limiting the transmission of torsional vibrations produced by the engine to a negligible amount.

2) Since there is no mechanical connection between the 2 members, the coupling permits a small amount of misalignment. This facilitates the erection of the propulsion plant and increases the reliability in service.

3) It acts as a quick disconnecting clutch which is not subject to wear, and the torque of which is independent of speed. Any engine can be disconnected in less than a second by interrupting the field current of its coupling. This permits repairs to be made without stopping the ship, and some of the engines can be shut down at low speeds to give greater economy. The greater reliability of multiple engine drives can be realized only if a disconnecting clutch is available to cut out a faulty engine, enabling the ship to proceed on the good engines. The use of the coupling as a clutch aids in maneuvering as described below.

4) The coupling limits the maximum torque to a safe value. The steady state pull-out torque is usually about 150% and the transient maximum torque on suddenly applied loads is about 200%. If trouble develops on one engine, such as a seized piston, the electric coupling will limit the torque transmitted to this engine to twice the normal value, and will permit it to stop without injuring the gear and with minimum damage to the engine.

The ease with which electric couplings can be connected and disconnected enables them to be used in maneuvering the ship in a manner which is impossible with other forms of couplings. When a large amount of maneuvering is to be done at low speed, as in going through a close channel or approaching or leaving the dock, the ship can be maneuvered entirely by the use of the couplings. This is done by running half of the engines ahead and the other half astern. The propeller can be connected to either group of engines by energizing the corresponding couplings, and the ship closely controlled by one coupling control lever. This system saves on starting air for the engines, and approaches the Diesel-electric drive in convenience. Fig. 55 shows a diagrammatic arrangement.

The couplings can also be used to reverse the propeller in reversals from full ahead to full astern, as in a "crash stop." In such a reversal, the coupling excitation is removed and the engines reversed. After they are running on fuel at reduced speed in the astern direction, the coupling fields are energized, and the coupling torque reverses the propeller. Fig. 58 shows a test slip torque curve on a coupling and a typical propeller torque curve during reversal, assuming that the engines have been brought to 60% speed in the astern direction before the couplings are excited again. It is evident from the curve that the coupling has sufficient margin in torque to reverse the propeller in a short time. This system of reversal is most advantageous on engines which do not have full torque available for reversal. By disconnecting the engine from the inertia of the gear, coupling fields and propeller, they can be reversed very quickly, even with rather low torque available, because the inertia to be accelerated is low. With the engine on fuel, full torque becomes available to reverse the heavy inertias of the system and overcome the propeller torque. If the engine has sufficient reversing torque, the maneuvering can be done entirely with the engine, with the coupling acting like a solid coupling.

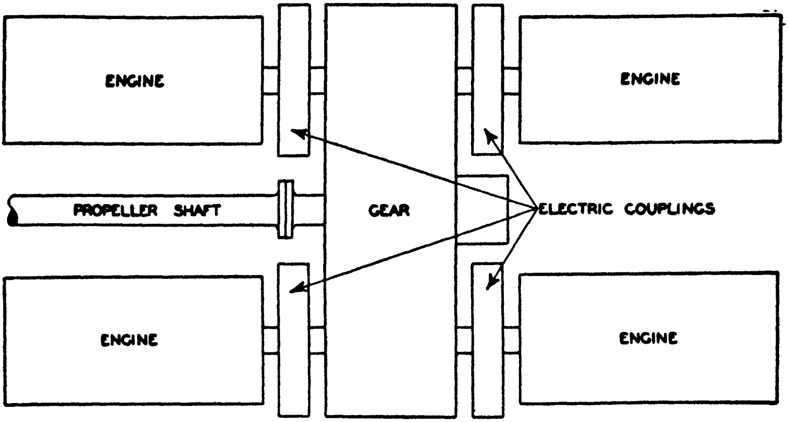


FIG. 55. Arrangement of 4-engine geared ship propulsion drive for C-3 cargo vessels, rated 8500 shaft HP.

## CHARACTERISTICS

**Losses.** There are only 3 losses in electric couplings—windage, slip or armature *IR* loss, and excitation or field *IR* loss. The core loss is usually negligible, as the operating frequency is ordinarily less than one cycle per sec. The core loss is included in the measured slip losses. The slip varies with speed and rating, but is ordinarily between 1 and 2%. The field loss has about the same magnitude, so the efficiency varies from 95 to 98% depending on the rating. The coupling illustrated in Figs. 56 and 57 tested just under 1.1% slip and 97.75% efficiency.

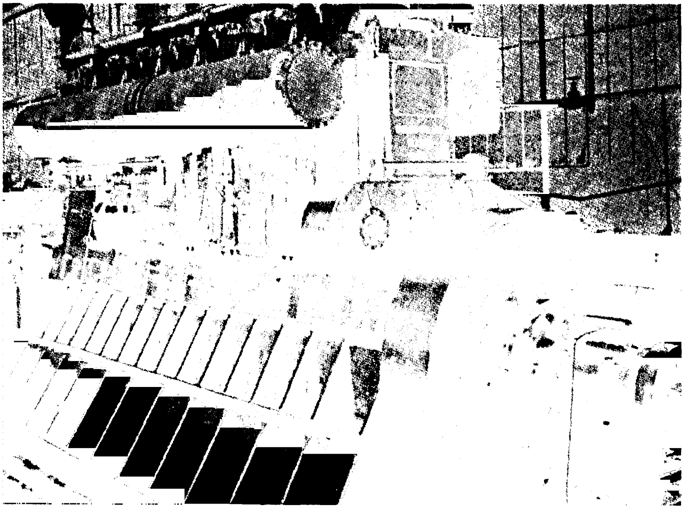


FIG. 56. Electric coupling, mounted on 2225-HP, 240-r.p.m. Diesel engine on shop tests. Built for the C-3 cargo vessels (see Fig. 55).

**Torques.** The torques required are determined by the operating conditions for the particular drive. The Maritime Commission engineers realized the full possibilities of using the electric coupling for maneuvering. They specified a minimum torque of 75% for any slip up to 140% to give the coupling some margin in torque over that required by the propeller during reversal. They also specified 150% pull-out, or maximum torque as being sufficiently high to cover all conditions of operation. To obtain high torques at high slips, and at the same time maintain low slip at normal load and minimum weight and space, is a real design problem. Earlier couplings employed single deck squirrel cages, although some of them used deep bars. The torques of these couplings at high slips were far below the values necessary to reverse the propeller at full ship speed. All couplings being built to the Maritime Commission specifications employ some form of double deck squirrel cage armature winding to increase the resistance at high slips.

**Temperatures.** All recent couplings have had guaranteed temperature rises of 70° C. by resistance, above an ambient of 50° C. These are standard for Class B insulation on electrical installations in ship engine rooms. This rise applies only to the field, as in the squirrel cage type of armature there is no insulation, and the temperature is limited solely by mechanical considerations. It is customary to require that the coupling meet the guaranteed temperature rise when transmitting full torque down to 70% of normal speed. This speed was chosen as it is the speed obtained with full torque on half of the engines, and was considered the most severe operating condition likely to be encountered. Theoretically, it would be possible to operate with full torque at half speed when running on one engine of a 4-engine drive, but it was not considered that this would be an operating condition. With Class B asbestos and mica insulation, the machine is practically incombustible and offers much less fire hazard than any device using oil.

**Torsional characteristics.** In the cases studied so far by the authors, the electrical coupling has effectively limited the transmission of torsional vibration from the engine to the gears to negligible values. It has also had negligible effect on the critical speeds of the engine. In information previously published about electric slip couplings, it has been said that the coupling does not transmit the torque pulsations originating in the engine. Strictly speaking, this statement is not exactly true, because the electric coupling under the influence of pulsating torques acts as a weak elastic member, or a torsional spring of low spring constant. This spring constant has a negligible effect on the natural frequencies of the engine and at the same time effectively limits the vibrations transmitted from the engine.

**Structural features.** The coupling illustrated in Figs. 56 and 57 is typical of large marine couplings made in this country, especially those for Maritime Commission vessels. The 2 members are overhung on the gear and engine shafts. Most of the couplings have the inner member mounted on the engine shaft, but the coupling will transmit torque in either direction and the field can be put on the engine. The arrangement to be used depends largely on the amount of inertia desired by the engine manufacturer for satisfactory operation of the engine and the most advantageous placing of the critical speeds.

The field has the poles bolted to the inside of the rim of a fabricated steel spider. The spider has a flange for bolting to the pinion shaft. The field is put on the outer member because such an arrangement gives

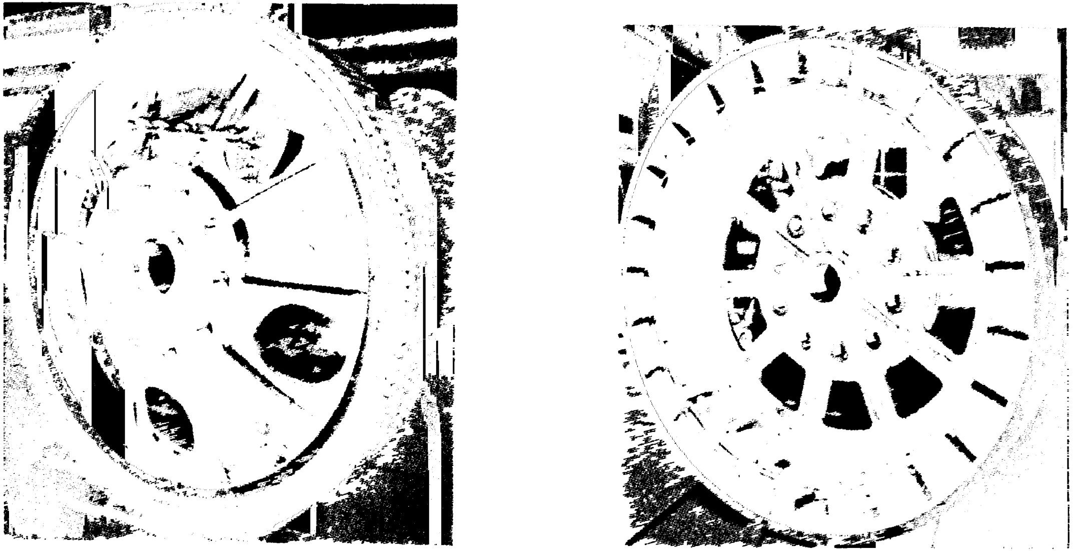


FIG 57 *A*) Field member of coupling shown in FIG 56 *B*) Armature or squirrel-cage member of coupling in Fig 56

more room for the winding, better ventilation, and more accessibility for replacing coils. The coils are made of edge-wound copper strap with Class B insulation of the same type almost universally used in large AC motors and generators, representing the most rugged construction available. Repairs can be made quite easily by unbolting the pole, sliding it out axially, and installing a spare field coil. The collector rings are bronze and the collector assembly is split for ease of removal. The field

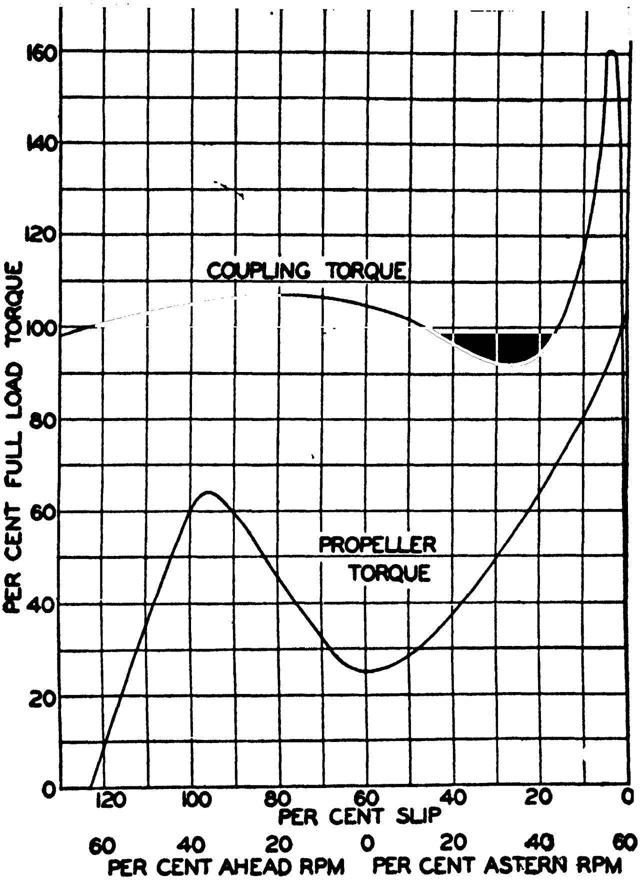


FIG. 58. Test slip-torque curve of coupling shown in Figs. 56 & 57.

is ventilated by air which is taken in through holes in the spider plate, passes axially along the windings, and is discharged at the open end.

The inner member consists of a fabricated spider which has a flange for bolting to the engine crankshaft flange. The core is made of one piece circular punchings shrunk on the rim of the spider. The winding is a double deck squirrel cage with separate short-circuiting end rings for each layer. The outer layer of high resistance bars is generously proportioned to absorb the heat produced during reversal of the propeller, since at high slips most of the loss is in the outer layer.

The coupling can be removed or assembled without disturbing the crankshaft or pinion shaft. Provision has been made to move the 2 members together axially a sufficient amount so that they will clear the spigot fits. In this position, they are centered together by a centering fit and can be bolted together. The entire unit can then be lifted out between the 2 shafts.

A screen guard is usually placed around the coupling for the protection of the engine room personnel. The brushholder parts are mounted on the gear case. The couplings take their excitation from the ship auxiliary power supply. The control consists of a selector switch operated by the coupling control lever at the engine control station, ammeters to indicate the field current, circuit breakers in each coupling circuit for short circuit protection, and suitable magnetically operated contactors. Discharge resistors are provided and also a resistor to reduce the coupling field for long operating periods at low speed and low torque. The necessary interlocks are provided to prevent energizing a coupling when the corresponding engine is shut down.

The size and weight of a coupling of given rating increase quite rapidly with the air gap. The minimum gap which can be used is determined by the possible maximum unbalanced magnetic pull. The unbalanced magnetic pull acts in a radial direction and is proportional to the displacement for magnitudes of displacement encountered in normal operation. It acts to increase the displacement, so is equivalent to a negative restoring force.

## DESCRIPTION OF OPERATION OF ELECTROMAGNETIC COUPLING CONTROL

Refer to Fig. 59 in relation to the following, which is the description of the electric coupling control manufactured by the Westinghouse Co.

The magnetic fields of the 2 couplings are energized from a 240-volt DC bus by means of type **AB** circuit breakers and magnetic contactors **1M** to **6M**.

The operation of the contactors is controlled by means of 4 cam-operated control switches located in the engine control stand. Two of the control switches are coupled to the engine starting levers and one switch is coupled to the coupling control lever. Each of these switches has 2 switch units, one of which will close when the corresponding lever is moved in "ahead" direction, while the other switch will close when the lever is moved in "astern" direction. In the "stop" position of the levers, both switch units are open. The fourth control switch is coupled to the clutch lever. Its 2 switch units will close when the 2 engine control levers are clutched together, and will open when the levers are de-clutched.

Assuming that the barring gear interlocks and the turning gear interlock are closed, and that the control switches on the gage board are placed in position for "full excitation," the control will function as follows:

**A. Operation with starboard engine alone.** Start the engine by moving the engine control lever in "ahead" direction and then place the coupling lever in "ahead" direction. This will establish the following circuit:

From the (+) supply bus through **AB** circuit breaker contact and its auxiliary switch to wire **14**, through gage board control switch and through coils **2M, 4M**, and **6M** to wire **9**, through interlock contact **1Ma** of contactor **1M**, which is closed when the contactor is open, through the starboard engine control switch **A** to wire **12**, through coupling control switch **A** to wire **6**, through turning gear interlock and finally to the (—) supply bus.

As a consequence, contactors **2M, 4M**, and **6M** will become energized. Contacts **2M** and **4M**, which are normally open, will close and connect the coupling field to the bus and short out the protective resistor **R1-R2.** Contactor **6M**, which is spring closed, will open and interrupt the field discharge circuit. The coupling is now energized and will turn the propeller at a speed determined by the position of the engine control lever.

To reverse the propeller, move the engine control switch to the "stop" position and then to the "astern" start position. The engine control switch **A** will thereby open, interrupt the coil circuits for contactors **2M, 4M** and **6M**, and de-energize the coupling. The engine control switch **B** will close, but the control circuit will not be re-established and the coupling energized until the coupling lever is moved to the "astern" direction also, thereby closing coupling control switch **B**.

**B. Operation with port engine alone.** The control circuit is similar to that for the starboard engine, with the exception that a control relay **CR** has been provided. This relay will become energized when the port engine lever and the coupling control lever are placed in Ahead or Astern direc-

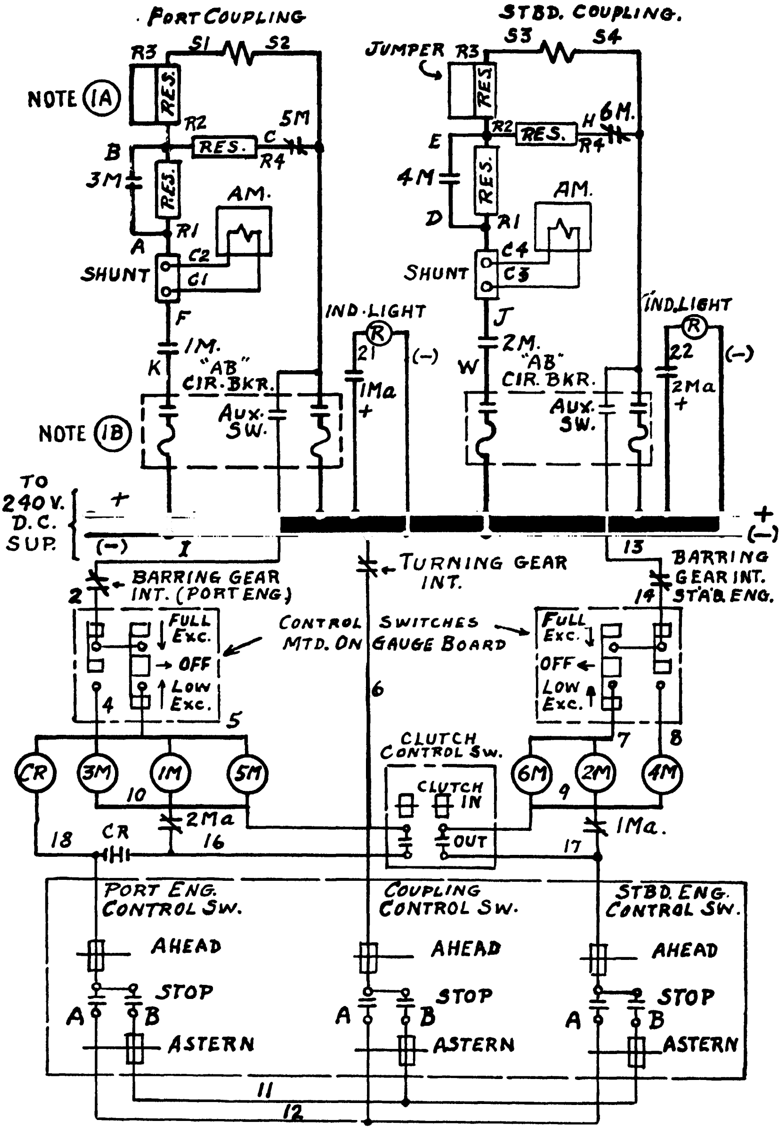


FIG. 59. Control wiring diagram of electromagnetic slip coupling installation on Diesel propulsion ships.

tion. The closing of the relay contacts will in turn energize contactor coils **1M**, **3M** and **5M** and energize the coupling.

The purpose of relay **CR** is to obtain a slight delay in the closing of the contactors so as to prevent momentary simultaneous closing of starboard and port contactors in case both engines are running but the engine levers are not connected together.

**C. Operation with two engines running in same direction.** Assuming that the port engine is running and coupled to the propeller and it is desired to couple also the starboard engine, the procedure is as follows:

Move the starboard engine lever to a position in the same direction as the port engine. This will start the engine and close the engine control switch, but the coupling will not become energized, as the interlock switch **1Ma** in the coil circuits of contactors **2M**, **4M** and **6M** opened when the port contactor **1M** closed.

To couple the engine, it will be necessary to bring the starboard engine up to the same speed as the port engine and clutch the 2 engine levers together. The clutch control switches will thereby close and complete the circuit to contactor coils **2M**, **4M** and **6M**. The contactors will operate and energize the starboard coupling.

To uncouple one engine, turn the corresponding gage board control switch to the "off" position and move the clutch lever to the "out" position.

**D. Operation with the two engines running in opposite directions.** This set-up is used when frequent reversals are required as, for example, when taking the vessel into or out of a harbor.

Assuming that the starboard engine is running in "ahead" direction and the port engine in "astern" direction, it will be seen that, when placing the coupling lever in "ahead" position, the starboard coupling will become energized and the propeller will turn in "ahead" direction. When moving the lever to "stop" position, both couplings will become de-energized and the propeller will stop. When moving the lever to "astern" position, the port coupling will be energized and the propeller will reverse.

**E. Continuous operation at low speed.** If the couplings are being energized for long periods when the engines are turning at low speeds, the field coils may become overheated. Under such conditions, it is recommended to reduce the field current. This may be accomplished by placing the gage board control switches in "Low exc." position. Contactors **3M** and **4M** will thereby become de-energized and resistance **R1-R2** will be inserted in the field circuit.

# IX

# INTERIOR COMMUNICATION

The subject of interior communication embraces all signaling and electrical indicating and recording devices, among which are: ship to ship, ship to shore, radio, intercabin telephone and telephone systems for the deck and engine room and the various alarm systems.

## TELEPHONE SYSTEMS

Current practice dictates the self-sufficient "sound powered telephone" which derives its power from a permanent magnet and a moving coil. This system is sometimes called a moving coil microphone or dynamic microphone. It is useful only for short distances, hence is limited to ships and buildings, etc.

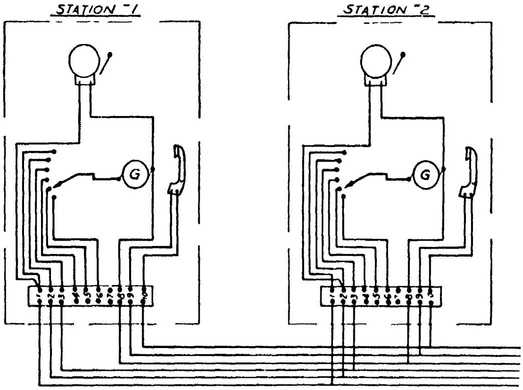


FIG. 60. Wiring diagram of telephone system.

Transmitters and receivers in such systems are generally designed to cut out as much noise as possible.

On merchant ships the usual arrangement is to have common talking and selective ringing, using a station selector switch and a hand-driven generator. This means that the talking circuit is composed of 2 wires and the ringing circuit of a common wire plus the same number of wires as station-selector switches. These usually provide for 8 stations.

Most of the cargo ships of the larger capacity being built today are provided with two separate telephone systems, one for the deck and one for the engine room. The engine room system will connect all stations which have machinery: the steering gear compartment, the chief engineer's office and the bridge.

The deck system connects the captain's office with the bridge and all deck stations, including the top of wheelhouse, the after steering station, radio room, lookout on the bow, steering gear room, etc.

These systems each have instruments at such important stations as the bridge and sometimes the engine room.

Fig. 60 shows how corresponding terminals are connected in parallel on each instrument. Equipment is designed for bulkhead and pedestal mounting, watertight and non-watertight. The pedestal type mounting is found on top of the wheelhouse and on the poop deck.

## RUDDER ANGLE INDICATOR

This system provides for a continuous indication of the position of

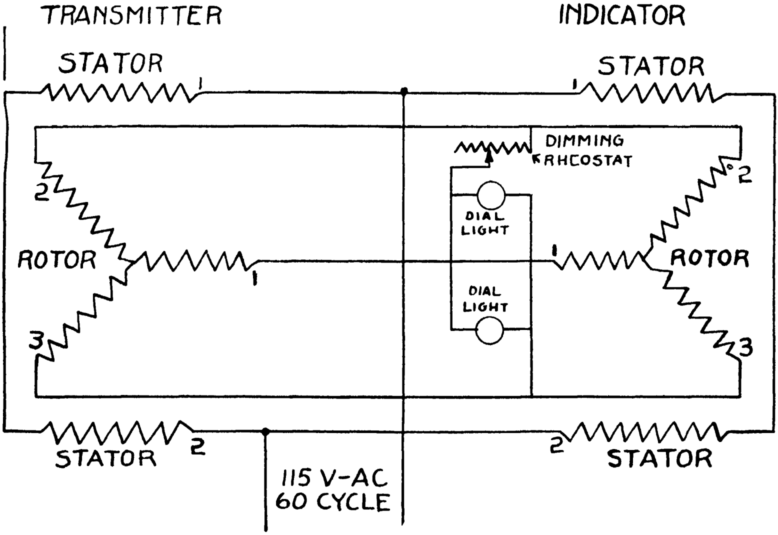


FIG. 61. Rudder angle indicator, circuit arrangement.

the rudder in the wheelhouse or any other station desired. To accomplish this, use is made of the self-synchronous system of transmission.

The equipment comprises 2 motors wound identically and their fields and armatures connected together. This arrangement, when energized with an alternating current, is such that the position of one motor is always assumed by the other: that is, if one motor is turned in either direction the other follows in step immediately. The energizing current is usually 115-v. AC 60 cycles. The circuit arrangement is given on Fig. 61. Lights are shown with a dimming rheostat for the indicator dial. Fig. 62 shows a diagrammatic layout.

## SHAFT REVOLUTION SPEED INDICATOR AND COUNTER

The shaft revolution indicator system consists of a transmitter motor and one or more receivers (indicators). The usual arrangement comprises a low voltage generator and a pair of cam operated contacts for the transmitter. This transmitter is driven by gears from the main propellor shaft. The voltage generated by the generator causes the

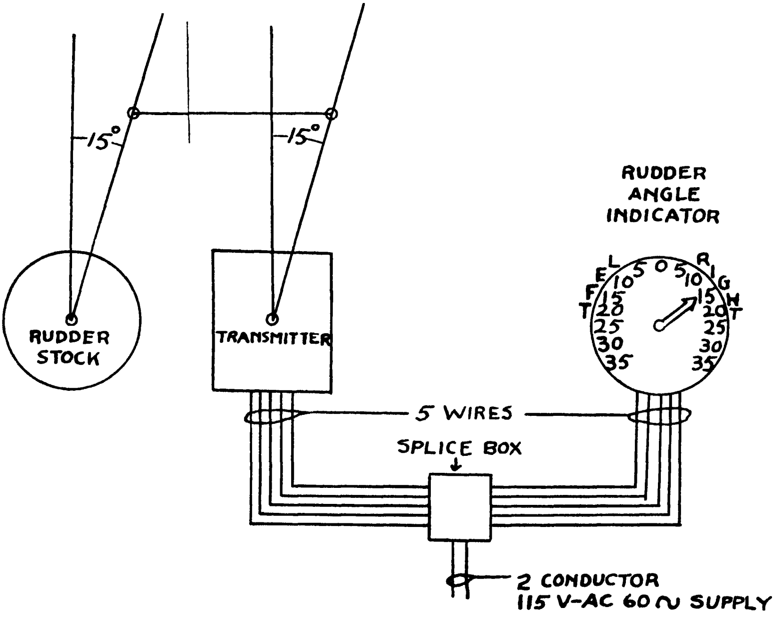


FIG. 62. Diagrammatic layout of rudder angle indicator.

needles of the indicating voltmeters (which are calibrated in r.p.m.) to move to the right or left, thus indicating whether the shaft is turning ahead or astern, and at what speed.

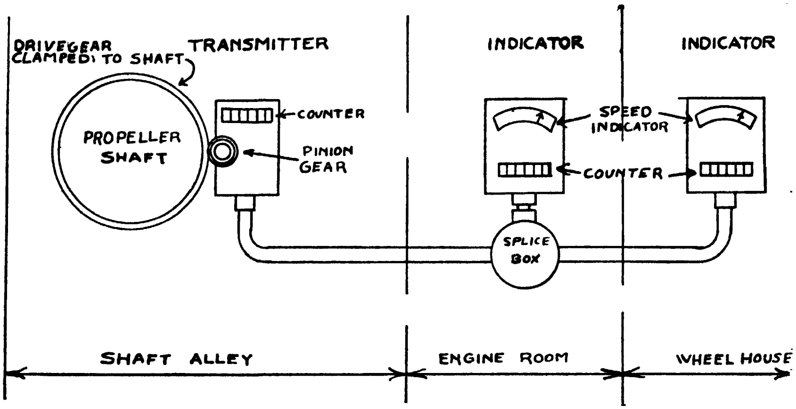


Fig. 63. Arrangement of speed indictor and counter.

The cam operated contacts in the transmitter close and open every revolution. This energizes the counter circuit and registers the number of revolutions made. These counters usually run to eight figures. Diagrammatic arrangement of equipment is shown on Fig. 63. Fig. 64 shows the wiring arrangement.

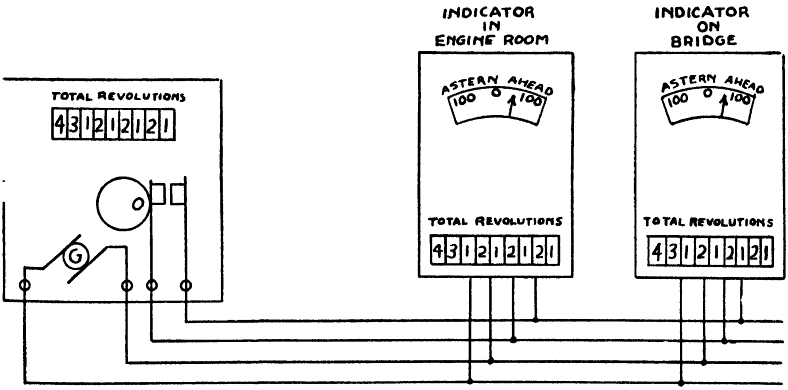


Fig. 64. Diagrammatic layout of speed indicator and counter.

## FUEL OIL FILLING HIGH LEVEL ALARM SYSTEM

High level alarm systems for fuel oil tanks will be found using annunciator and signal bell. The equipment is arranged as indicated on Fig. 65. The annunciator is usually mounted near the tank level in-

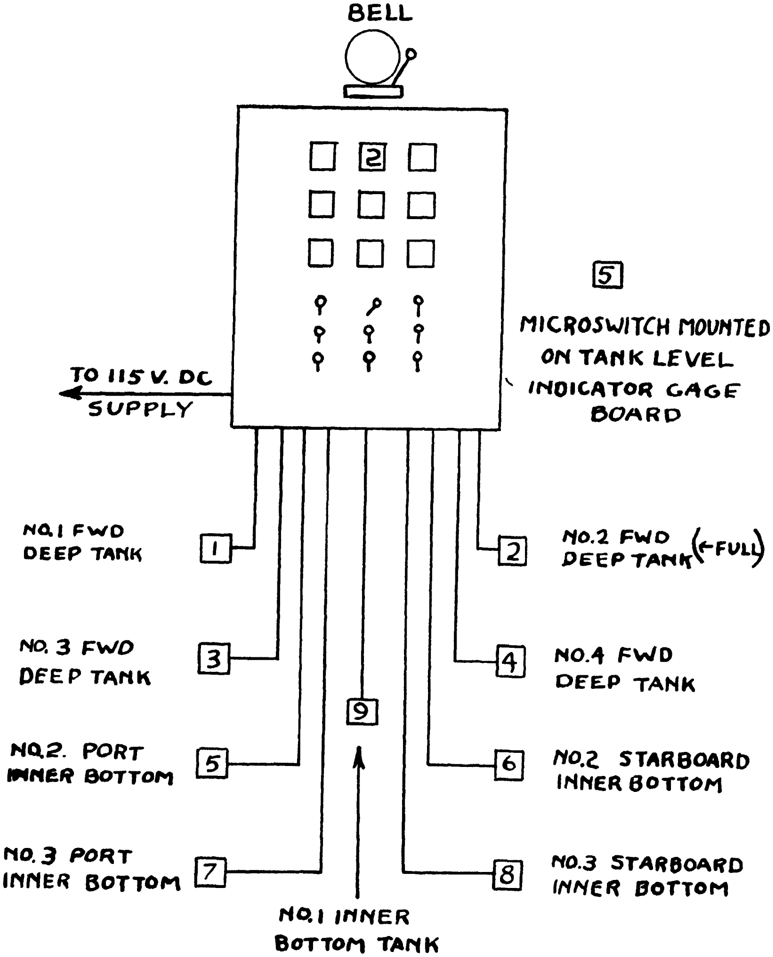


FIG. 65. Fuel oil tank high level alarm system arrangement.

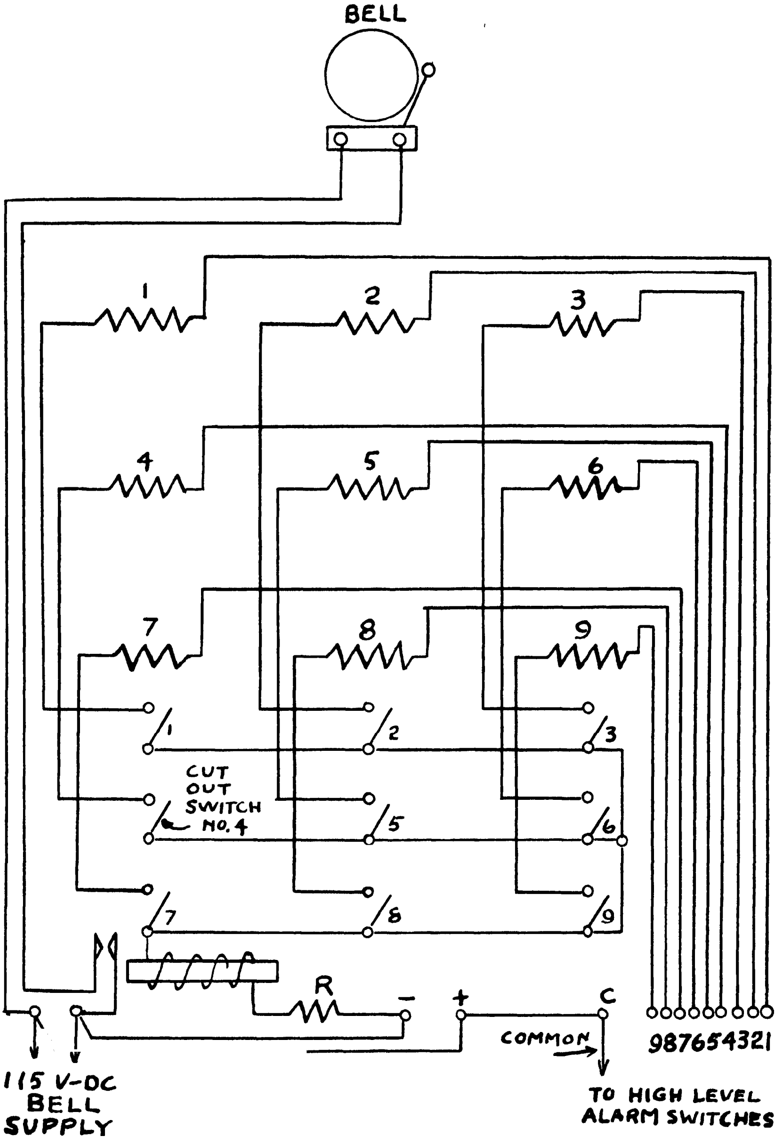


FIG. 66. Circuit wiring diagram of tank high level alarm system.

dicating gage board and fuel oil filling line valves. High level switches of the micro type are almost exclusively used. They operate at approximately 3 in. below full, which allows the operator time to shut off the filling line. The annunciators are of the common drop type, and are housed in a watertight case. A reset device is provided to 'clear' the board.

A cutout switch is provided for each drop circuit, so as to isolate it from the bell. When this switch is opened it de-energizes the bell relay. The bell stops ringing, but the drop remains down. This allows a common bell for all annunciator drops. The annunciators (both bell and drop) are operated on 115-v. DC. The drops are energized through a resistor **R** in series with the bell. In some cases the bell is operated from 115-v. AC or DC, and the drop circuit operated on 24-v. DC. The

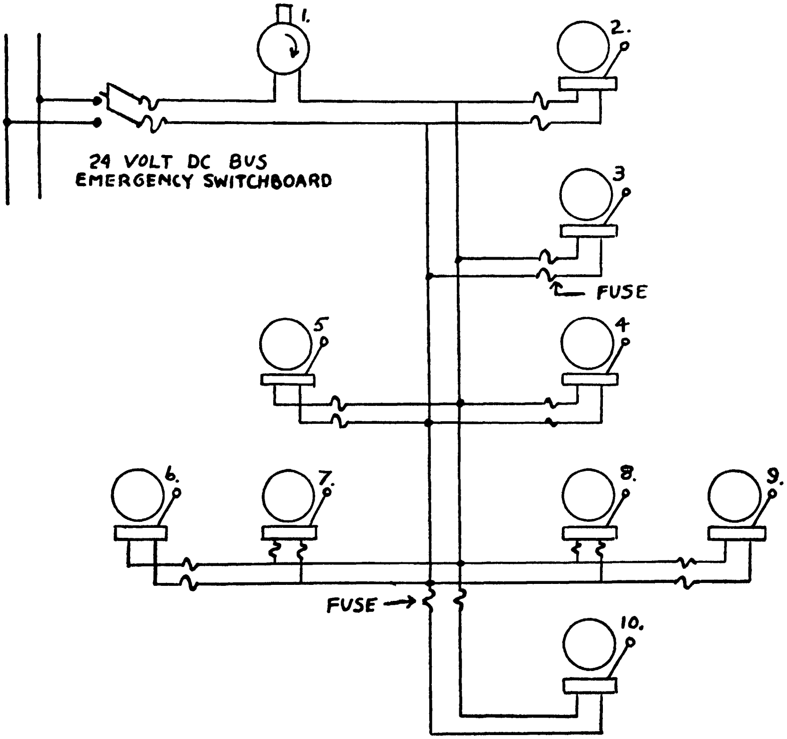


FIG. 67. Typical arrangement of general alarm system.

tanks indicated on Fig. 65 are typical. Signal gongs, operated by pushbuttons, are located at the filling station on deck and at the annunciator near the fuel oil valves below. The pushbuttons are arranged so that signals may be sent either way, notifying the crew on deck when the tanks are full. Fig. 66 shows the circuit wiring diagram.

## GENERAL ALARM

The general alarm system on both cargo and passenger ships is made up of a manually operated contactor located in the wheelhouse, or at a fire control station. Gongs of the vibrating type, 8 in. or more in diameter, are used. These gongs are separately fused, and located where they may be heard by the crew at all times: in refrigerated spaces and galley, and all passageways adjacent to and in the quarters. The general alarm power supply is taken from the 24-v. DC bus on the emergency switchboard. Fig. 67 shows a typical arrangement of the general alarm system.

## COLD STORAGE SPACE ALARM

To protect anyone who may become locked in the cold storage area, and as a general safety measure, an alarm is provided which operates from

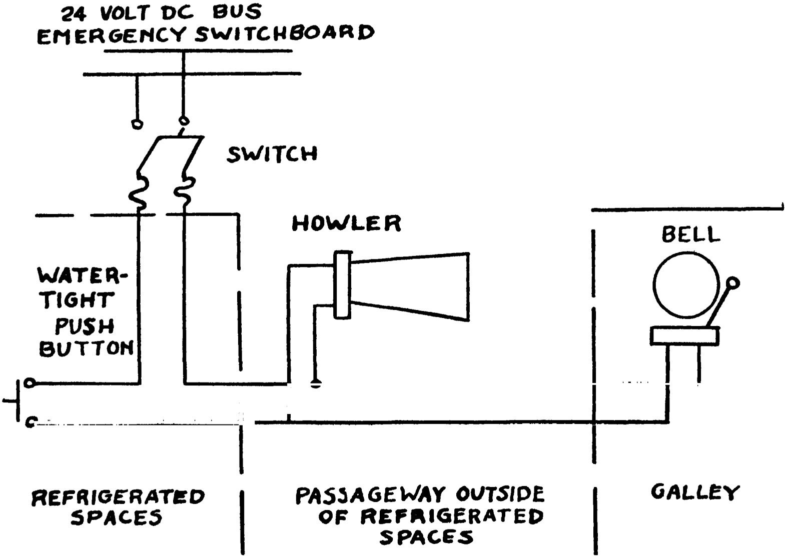


FIG. 68. Cold storage alarm system arrangement.

within the cold storage area. This alarm is made up of a howler operated from the 24-v. DC bus on the emergency switchboard and a bell of the same voltage, connected in parallel with the horn. The howler is

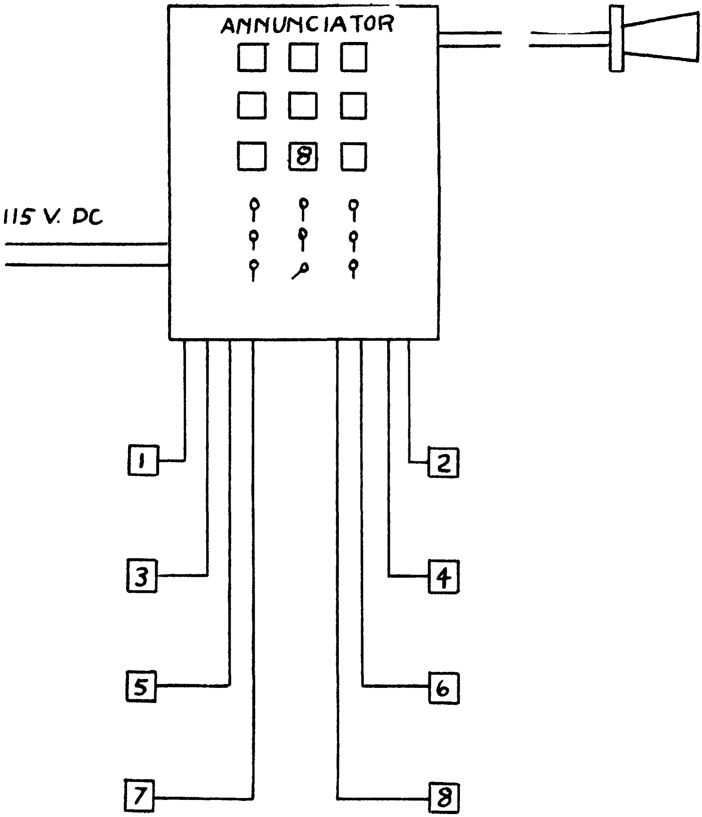


FIG. 69. Engine alarm system circuit.

usually located in the passageway adjacent to the refrigerated area, and the bell is located in the galley. (See Fig. 68.)

In addition to the above, a red light is provided, wired in parallel with the lights in the refrigerated area but located just outside the cold storage door. This red light is always on when the lights are on in the cold storage spaces.

## ENGINE ALARM SYSTEM

This system is used as a safeguard against failure of the lube oil and cooling water circulating systems. It is comprised of a system of contactors and audible and visual signals. A bell or howler may be used with lights for indicating each trouble, with switches to cut off the howler.

Annunciators are also used, and provide a convenient indicating device, mounted near or on the gage board. The howler will usually be found at a point where it can be heard throughout the engine room. Fig. 69 shows an annunciator and howler using a circuit similar to that shown in Fig. 65.

The system indicated on Fig. 69 is for a single screw cargo ship with two Diesel engines and a reduction gear. Two electric generator Diesel engines are included in the alarm system.

## ELECTRIC WHISTLE CONTROL

Present day practice makes use of both air and steam whistles. The valves of these whistles are of the solenoid operated type.

When it is desired to blow the whistle for a sustained period of time, using a series of long blasts, etc., an electric timer of the cam operated contactor type is used.

To operate the whistle "at will" (directly) or "automatically," using the electric timer, an "automatic-at will" switch is provided. It is usually located in the wheelhouse and at the port and starboard bridge wings.

When these "automatic-at will" switches are operated in the automatic position they remain in this position and blow the whistle with the timer, only stopping when the handle of the switch is returned to the neutral position. When it is desired to blow the whistle in some particular manner—such as 3 short blasts—the switch is pulled to the "at-will" position 3 times for a short interval each time. The switch returns by spring to the neutral position from the "at will" position. A transfer switch is provided to transfer from air to steam whistle and vice versa.

Fig. 70 shows a typical circuit arrangement of the timer, transfer switch and "automatic-at-will" switches.

## STEERING GEAR ALARM AND INDICATOR CIRCUITS

This circuit is comprised of four relays each having two separate sets of contacts.

Referring to diagram, Fig. 71 and considering only the port motor: when the port motor is started the voltage applied to the motor is also applied to the coil **A** and its associated green light.

The light lights and the **A** coil is energized thereby opening the **A** contact in the bell circuit and closing the **A** contact in the **C** coil circuit, coil **C** is energized and both **C** contacts close.

Now if for any reason the voltage applied to the port motor fails the **A** coil is de-energized and its green light goes out. The **A** contact in the bell circuit closes and the bell rings and the red light lights.

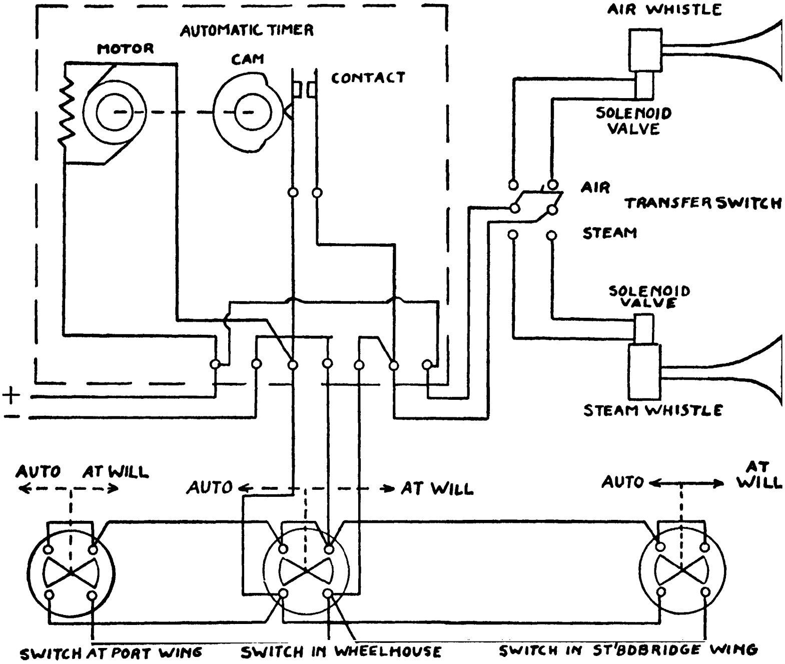


Fig. 70. Typical circuit arrangement for whistle control system.

The operator may then shut down the alarm by pressing the silence and reset button. In the same way the alarm for the starboard motor operates, using the **B** and **D** coils and contacts.

The equipment is usually mounted on the main switchboard with the red light located at the engine control station or on the main switchboard.

## PYROMETERS

The pyrometer (Fig. 72) is a temperature indicating device and is used for measuring temperatures above those usually measured by the glass mercury type thermometer.

The pyrometer is comprised of a thermocouple and an indicating instrument which is a millivoltmeter calibrated in degrees of temperature, Fahrenheit or Centigrade.

The thermocouple is made of dissimilar metals fused together which, when heated, generates a small voltage. This voltage is proportional to the temperature, and when used with a millivoltmeter will show the temperature.

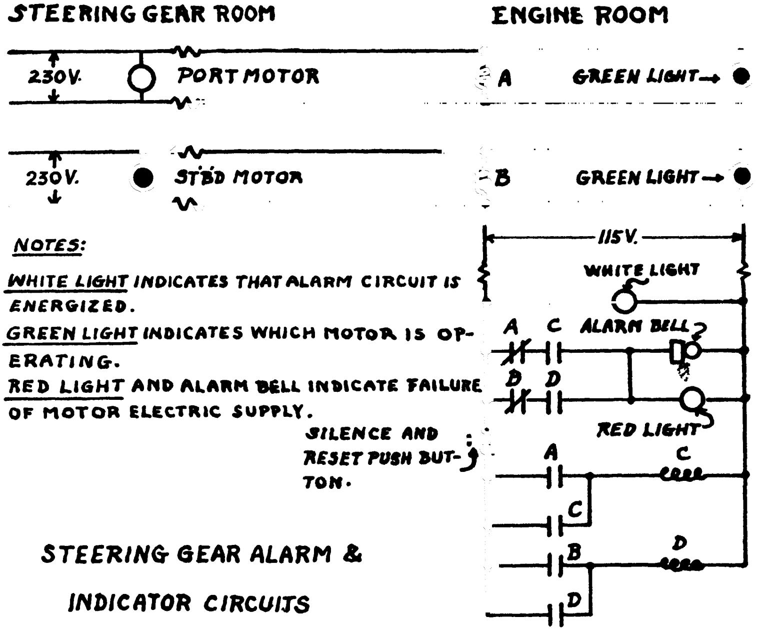

STEERING GEAR ROOM
ENGINE ROOM
230V.
PORT MOTOR
A
GREEN LIGHT→
230V.
ST'BD MOTOR
B
GREEN LIGHT→
NOTES:
WHITE LIGHT INDICATES THAT ALARM CIRCUIT IS ENERGIZED.
GREEN LIGHT INDICATES WHICH MOTOR IS OPERATING.
RED LIGHT AND ALARM BELL INDICATE FAILURE OF MOTOR ELECTRIC SUPPLY.
SILENCE AND RESET PUSH BUTTON.
115V.
WHITE LIGHT
A
C
ALARM BELL
B
D
RED LIGHT
A
C
C
B
D
D
STEERING GEAR ALARM & INDICATOR CIRCUITS

FIG. 71.

The metals used are iron and constantan for continuous service at temperatures from 0° to 850° C. Chromel and constantan are also used for this range. Chromel and alumel are used on temperatures up to 1000° C. and slightly over.

The thermocouples are supported on porcelain or quartz insulators and enclosed in special steel tubes. These tubes are known as thermowells. The thermowell is installed in the desired location, the thermocouple screwed in place and the terminals connected to the selector switch. This arrangement permits the use of one instrument (indicating voltmeter) and many thermocouples.

On shipboard, and particularly on ships having Diesel engines, the pyrometer finds constant use. Fig. 73 shows a typical circuit arrangement for the indication of exhaust temperatures.

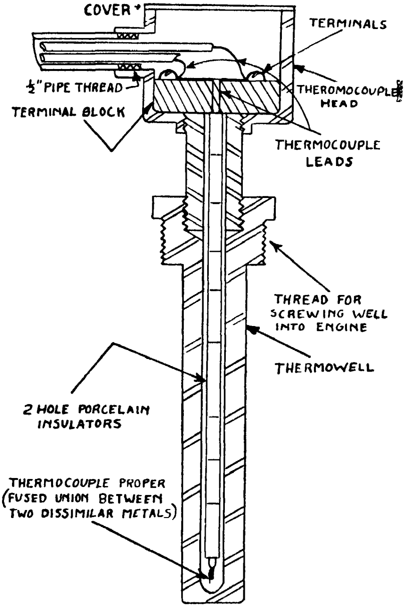

COVER
TERMINALS
½" PIPE THREAD
TERMINAL BLOCK
THEROMOCOUPLE HEAD
THERMOCOUPLE LEADS
THREAD FOR SCREWING WELL INTO ENGINE
THERMOWELL
2 HOLE PORCELAIN INSULATORS
THERMOCOUPLE PROPER (FUSED UNION BETWEEN TWO DISSIMILAR METALS)

FIG. 72. Cross section of pyrometer.

## RUNNING LIGHT CONTROL PANEL

The ship's running lights (masthead, port and starboard lights, range light and overtaken light) are controlled from the wheelhouse by a special panel.

The lamps used in these lights are of the double-filament type (although 2 single-filament lamps may be used). The function of the control panel is to provide a means of switching on and off the running lights and also of changing over to the other filament or lamp when the active one burns out. This operation is accomplished manually or automatically, depending upon the design of the panel.

The filament circuit of light is comprised of 3 leads, 1 common and 2 returns (one for each filament or lamp). These 3 leads terminate in the control panel, as indicated in Fig. 74. Each filament (or separate lamp) is individually fused

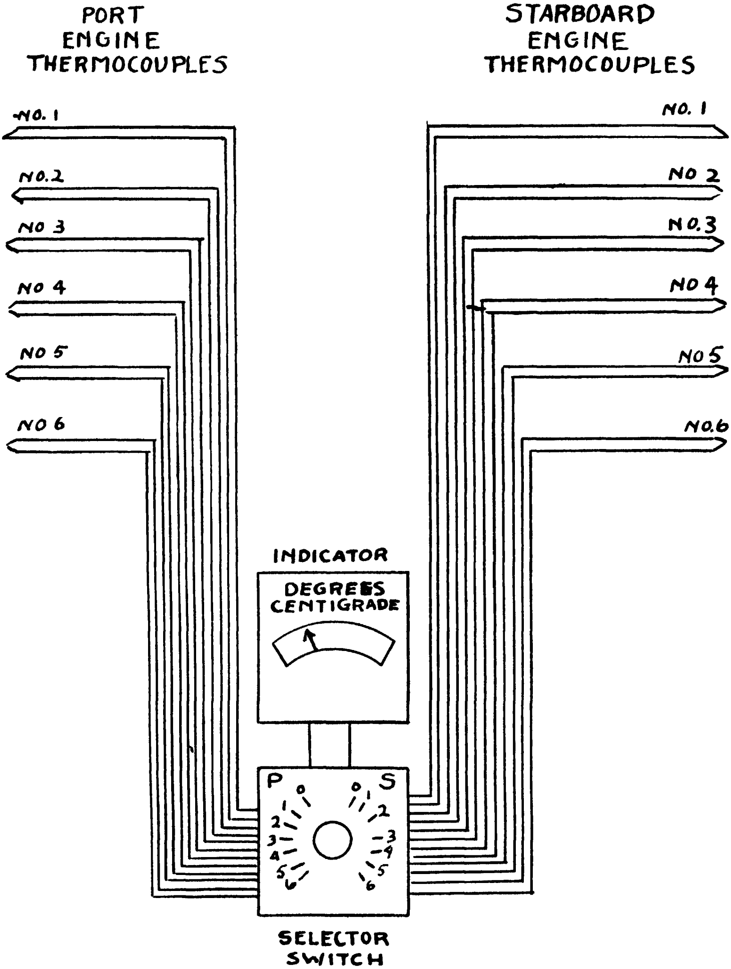


FIG. 73. Typical pyrometer system, circuit arrangement.

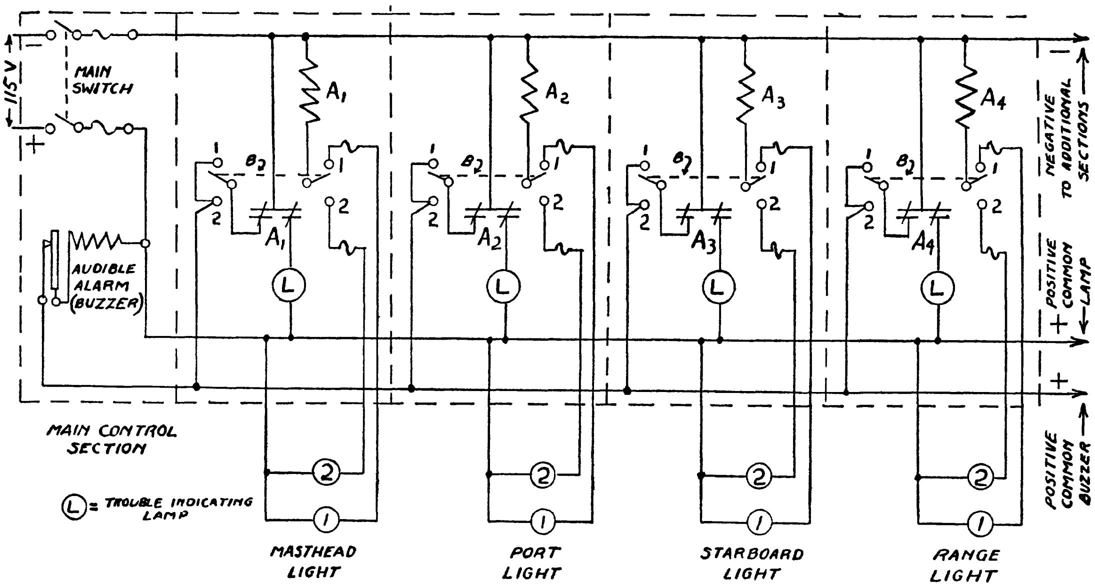


FIG. 74. Wiring diagram of running light control panel

The operation of the panel is as follows:

Close the main switch. This energizes all the adjacent sections. Move all switches (double pole-double throw) marked **B** to No. 1 position. This will light the No. 1 filament or lamp in each of the connected lights.

Since coil **A** of the trouble relay on each section is in series with the filament which is controlled by that section, the filament current flows through coil **A**. This operates the trouble relay contacts marked **A**, and they hold open as long as the filament is lit.

This is the normal running position.

If any filament burns out, the coil **A** in series with it is de-energized, and the **A** contacts close. This in return puts the supply voltage across the trouble lamp **L** associated with the burnt-out light, and the audible signal (buzzer) located in the main section begins to operate.

Throw the switch marked **B** on the section where the trouble light is "On" to the No. 2 position, and the second filament will be lighted. The trouble light will then go out and the buzzer stop sounding. Should the second filament also burn out, the trouble light will again light and the buzzer sound. In this case, replace the defective lamp.

The above arrangement is typical, and aids in understanding the general operation. Neon lamps are used in some designs as trouble indicators. Each section of the running light panel is clearly marked with the name of the light it controls.

Some ship designers recommend additional sections for the control of Morse signal lights and towing lights, etc.

## FIRE ALARM SYSTEM

The fire alarm system shown in Fig. 75 (Bendix-Cory type) consists of a series of thermostats, located at various points and connected electrically to an automatic, electrically supervised fire alarm circuit panel.

A green bull's eye pilot light always remains lit to indicate that the system is in operation.

In case of fire the heat causes the thermostat to close an electric circuit to the panel, ringing the 6-inch bell and dropping two red flags, one on the master section indicating the bell circuit is closed and one on the line section indicating the location of the fire. Opening the panel door stops the bell ringing and causes the red flag on the master section to go back to normal, but leaves the red flag on the line still showing.

Switches on the panel test both fire and line trouble alarm operation. To test for fire push the fire test switch upwards. When this is done fire conditions are duplicated and the line flag should drop, indicating that the fire alarm circuit is in operating condition.

To test for line trouble, push the fire test switch down. This should cause the small pilot light over the switch and the trouble light on the master section to operate, as well as the buzzer

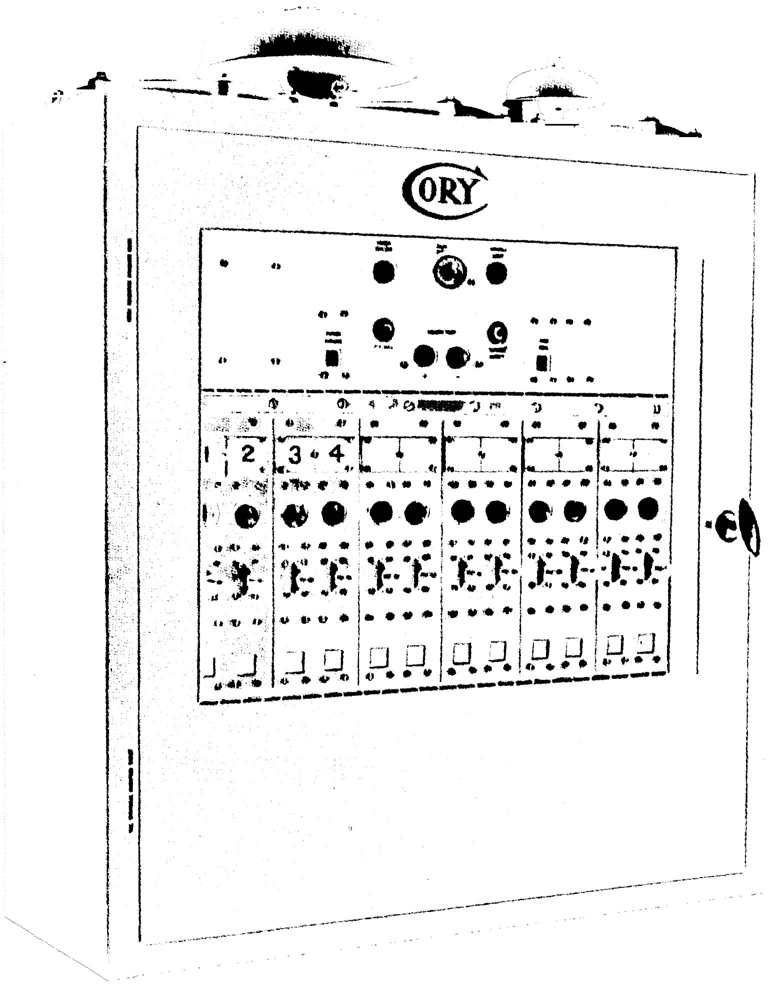


FIG. 75. Bendix-Cory fire alarm system control panel.

## TELEGRAPHS

Electric telegraphs are made in several types, suitable for various applications such as engine, docking, steering and fireroom orders. They are furnished with single or double face heads, and with or without reply and for single or double engine installations.

One common type of telegraph is operated by means of a pair of self-synchronizing motors. The transmitter handle is connected mechanically to one motor, which in turn is connected electrically to the indicator motor. When the transmitter handle is moved, the pointer on the indicator dial follows the movement within 1° of arc. Transmitter and indicator are connected by an electric cable.

## SELF-SYNCHRONIZING MOTORS

The self-synchronizing motor (also called Autosyn and Selsyn) is used in pairs for communication and control systems between local and remote stations.

This motor has a single-phase wound stator which is connected to 110-v. AC for excitation. The transmitting rotor, which is of the 3-phase Y-wound type, is connected directly to the rotor windings of the associated motors, whose rotors are also Y-wound. The slightest angular displacement of the transmitting rotor causes the associated rotors to seek synchronous position. An accuracy of 1/2° may be maintained. These motors have an approximate maximum torque of 20 ounce-inches at 90° angular displacement. Safe continuous operating torque is 8 ounce-inches.

These motors are used in conjunction with engine order telegraphs, docking telegraphs, rudder angle indicators, voltage regulators, pressure recorders, etc., some of which are treated above.

## FATHOMETER

The fathometer or echo sounding machine is an instrument for determining the depth of water. The fathometer consists of an oscillator that produces a sound, a hydrophone for receiving the echo, and a suitable device for measuring the elapsed interval of time and indicating the depth of water. The echo sounding machine possesses a distinct advantage over the usual type sounding machine, in that soundings may be obtained almost instantaneously, and as frequently as desired by the navigator. Fig. 76 shows the principal parts and method of operation of the fathometer.

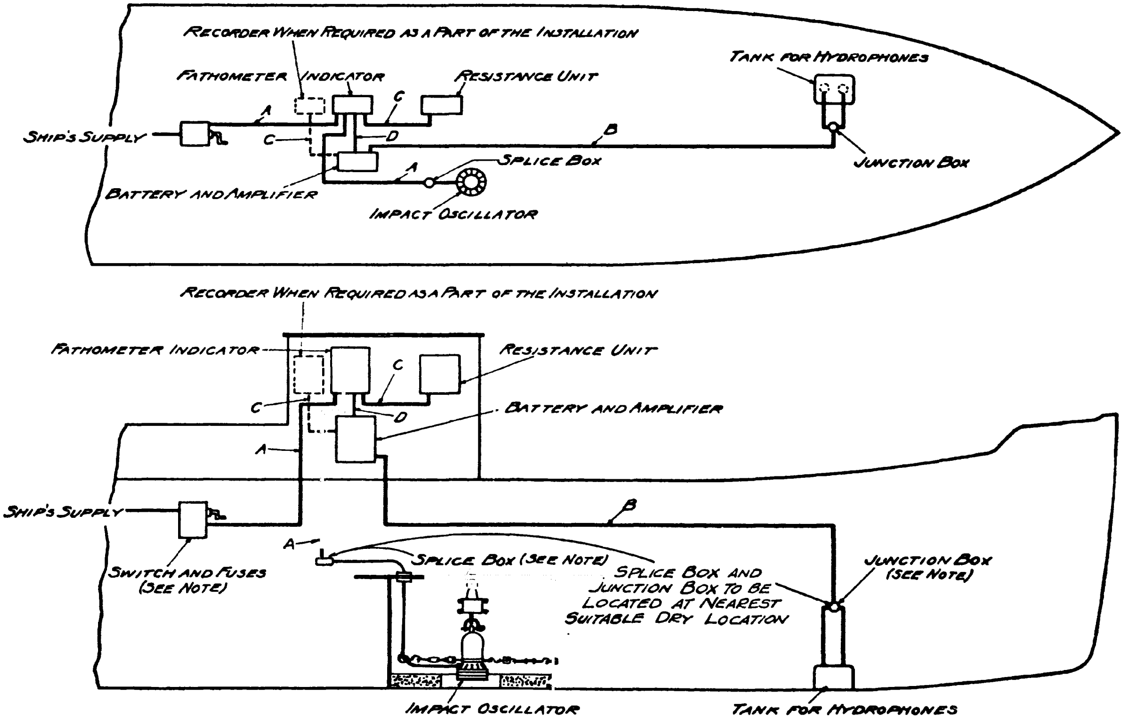


FIG. 76. Parts and layout of typical hydrophone. Cable *A* has two 13,000-CM conductors, Cable *B*, 3 twisted pairs, 1600-CM, Cable *C*, five 4000-CM and Cable *D*, ten 1600-CM. *Note:* Cables *B* and *D* must be kept at least 6 ft. distant from Cable *A* and all other cables carrying fluctuating loads wherever the cables run parallel.

# X

# MAINTENANCE

## INSPECTION

The first requirement in the satisfactory maintenance of electrical apparatus is competent inspection.

General conditions should be determined by a thorough initial inspection, after which a systematic maintenance schedule should be established. This schedule should include periodic routine inspections. The best time to inspect apparatus is while it is being cleaned.

**Inspection equipment.** The equipment available for inspection should include the following:

Extension lines and flash lights, special tools for disassembling apparatus, air-gap gages, spirit level, inside and outside micrometers, test indicator (truth gage), megger or ohmmeter, electrical instruments, thermometers and magnifying glass. The industrial analyzer shown in Fig. 77 is an extremely useful testing unit.

The electrician should also be provided with the manufacturer's instruction books pertaining to the apparatus which he examines, and with diagrams of connections and any drawings that may be necessary for the satisfactory performance of his duties.

**Inspection records.** Inspection dates and information concerning the condition of apparatus should be recorded. A card form to be filled in with figures and symbols will be found most convenient for routine inspection records. Special records covering cleaning, drying, varnish treatments and repairs, or re-construction, are very desirable. Changes in operating conditions or in the location of apparatus should be reported. Dates are important.

**Cleaning.** Clean apparatus will give the best and longest service. Not only should electrical apparatus be protected against dirt and moisture, but also against oil (which always collects dirt), acids, alkalis, chemical compounds, gases, etc., which may cause deterioration of the insulation or corrosion of the metal parts.

It is recommended by the American Institute of Electrical Engineers that the insulation resistance of stator windings and armatures of clean, dry machines at approximately 75°C. should not usually be less than given by the formula:

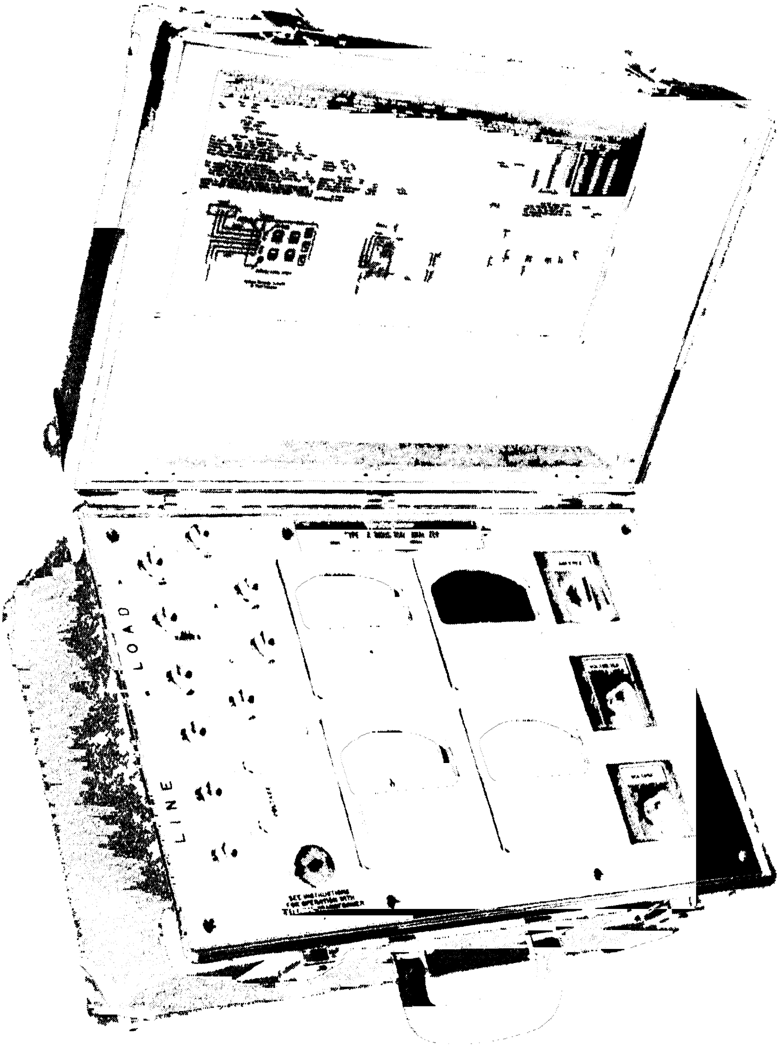


FIG 77 Industrial analyzer, testing kit for testing AC motors and circuits A similar set is made for DC work Instructions come with each kit

$$\begin{array}{c}\text{Insulation resistance}\\ \text{in megohms}\end{array} = \frac{\text{Rated voltage of machine}}{\dfrac{\text{Rating in Kv-a.}}{100} + 1000}$$

The minimum insulation resistance of the field should be of the order of one-half to one megohm, depending on the size of the machine. It is the rather general practice of insurance companies to demand an insulation resistance of one megohm per 1000 v. operating voltage, with a minimum of one megohm, for apparatus that is insured.

The method of taking resistance measurements is given on page 199.

**Operating temperatures.** Due to inherent characteristics of insulating materials in general, high temperatures shorten the operating life of electrical apparatus. The total (or actual) temperature, not the temperature rise, should be the measure of safe operation—a relatively low temperature rise with a very high ambient may result in rapid deterioration of insulation. When either the windings or the bearings of a machine not specially designed for high temperature service attain temperatures in excess of 90° C., the operating conditions should be investigated. The cause of gradually rising temperatures during a considerable period of time should be found and abnormal conditions should be corrected. Sharply rising temperatures generally warrant a shut-down and a thorough examination of the apparatus.

**Specific apparatus.** Subsequent sections will cover maintenance procedure on various types of electrical apparatus. It is the intention here to list only such rules for the inspector as apply in a broad, general way to rotating electrical equipment and circuit breakers.

## ROTATING APPARATUS

**Voltage checks.** Unbalanced voltage may seriously affect the operation of sensitive apparatus, and single-phase operation is almost certain to result in damage to polyphase motors. Voltage readings taken at the terminals of a three-phase motor which will not start may be mis-leading, for even if one line is open at the transformer or starter, voltage will be indicated between all three lines at the motor if another three-phase motor has continued to run single phase on the same circuit.

1) A variation in voltage not exceeding 10% is generally permissible.

2) Higher voltage will result in decreased power factor, increased torque, decreased slip, decreased efficiency, and increased temperature.

3) Lower voltage will result in increased power factor, decreased torque, increased slip, increased efficiency and decreased temperature.

**Current collectors.** Proper care of brushes, brush rigging and current collecting parts is a fundamental necessity—if satisfactory performance is to be obtained. Adequate inspection is an important part of the maintenance of this equipment. Observe the following points:

1) Brushes should be accurately adjusted and fitted to the commutator or collector rings.

2) Care should be taken to see that dirt, or particles broken from the edges of brushes have not lodged between a brush and the surface of the commutator or collector ring.

3) Brushes must move freely in the brushholders, but should not be so loose that "cramping" will occur when the machine is operating.

4) Check the spring tension, which should be 1½ to 2½ lbs.

5) The commutator or collector rings should be smooth and true.

6) There should be no objectionable vibration.

7) The brushes must be correctly aligned and the commutator brushes must be properly staggered, pairs of arms (+ and −) being set out and in alternately.

8) In general, the temperatures should be low and sparking or flashing should not occur.

**Lubrication.** Periodically scheduled and proper lubrication is always of paramount importance in rotating equipment, and will be treated in detail in a later section.

Checking the oil supply, the condition of oil rings and temperature of the bearing is the first duty of the electrician when checking a rotating machine.

**Mechanical details.** It is customary to think of failures in connection with electrical equipment as electrical or insulation troubles. Many such failures, however, are strictly mechanical, and a surprisingly large percentage—although electrical—are due to mechanical causes.

An unusual noise in electrical apparatus may be caused by vibration, due to—

a) Unbalance or bent shaft.

b) Obstruction of the ventilating system.

c) Loose parts.

d) Faulty alignment.

e) System disturbance, or many other abnormal conditions.

No simple device is available for locating the source of, or analyzing the noise. The action taken must depend upon the judgment and experience of the electrician.

**Air gaps.** Air gap adjustments are closely associated with bearing maintenance, especially so in the case of large machines when doing any work which may affect the alignment. Consult the manufacturer's instruction book in adjusting the alignment of large apparatus.

## TRANSFORMERS

The inspection of an oil insulated transformer that is in operation is necessarily confined to observing and noting the oil level, the temperatures as indicated by the gauge, noting at the same time both the air or ambient temperature, and load conditions.

If, for any reason, the condition of the oil is open to suspicion between the more detailed shut-down inspections, samples should be drawn and tested in line with procedure outlined in manufacturer's instruction book.

Any unusual noise should be noted for a more detailed investigation during a shut-down period.

In the case of water-cooled transformers, the rate of flow should be checked from time to time. If found to have diminished, the cause should be looked for and remedied.

## CIRCUIT BREAKERS

The main points to be observed in the inspection of an oil circuit breaker are—

1) Condition of the oil

2) Condition of contacts, both main and auxiliary

3) Checking the operating mechanism to make sure it works freely yet is positive in closing, latching and tripping

The electrician should—while observing their condition—lubricate pins and bushings subject to wear, see that all cotters are in place, and that all bolts, nuts and set screws having to do with the breaker structure are set tight.

Note carefully any evidence of heating, wipe off all breaker bushings, and check for cracked bushings.

The same general points should be observed in going over the operating mechanism of an air breaker, whether electrically or manually operated.

In the adjusting or fitting of contacts, the manufacturer's instruction book should be followed closely.

## INSULATION

Electrical insulation, or the medium separating conductors, has been defined as any non-conductor of electricity. However, materials commonly used as insulation are non-conductors only when they are clean and dry. This is characteristic of liquids and gases (including air), as well as of solid insulating materials.

Operating instructions provided by the manufacturers emphasize the importance of keeping electrical apparatus clean and dry. Favorable locations, suitable enclosures and adequate ventilation, drip-proof covers, splash-proof protection and heaters to prevent condensation when apparatus is out of service, all reduce interruptions and lower maintenance costs. However, when electrical apparatus does get dirty, insulation must be cleaned. Furthermore, to determine that insulation is clean and dry, it must be tested. This subject is covered on page 197.

## CLEANING

The method of cleaning insulation includes wiping off the dirt with a clean dry cloth; blowing it out with air pressure; drawing it off with suction apparatus; removing it in various ways with solvents, and washing it off with water—sometimes hot water and a solvent are required. The method will, of course, depend upon the type of apparatus and conditions involved.

**Wiping cloths.** When the apparatus is small, and only dry dirt has collected on exposed parts, cleaning with a dry cloth may be satisfactory. Waste should not be used, as the lint will adhere to the insulation and collect dust, moisture and oil. Dirt or moisture-filled lint is particularly objectionable on high voltage insulation as it tends to cause concentration of corona.

**Compressed air.** Blowing out dirt with air at about 50 lb. pressure is usually effective, particularly when the dirt has collected in places which cannot be reached with a cloth. Generally, cleaning can be done more quickly with compressed air than with a cloth. This applies especially to large apparatus. Do not direct compressed air against insulation until certain that it is free from moisture that may have accumulated in the air line from condensation. Too great an air pressure may loosen binding tape and blow dirt under it. Dirt blown out of a machine is likely to be drawn into others that are in operation near it. Remember, the use of compressed air simply transfers the dirt from one location to others and unless the final location is outside the operating room, very little good may be accomplished.

**Vacuum.** The old adage of an ounce of prevention is worth a pound of cure applies very well in the matter of keeping apparatus clean. Suction apparatus may be applied to give excellent results in collecting copper dust and other waste materials; as example, during the grinding of commutations and collector rings. Dust of this nature is highly conductive and if allowed to enter the windings of armatures, field coils, etc., it is sure to result in serious insulation failures.

A simple, effective and inexpensive device for collecting dust during the grinding of commutators and collectors is illustrated in Fig. 78, and can be made from three small pieces of equipment: (1) a four-foot length of 1½ in. rubber hose; (2) a vacuum bag similar to a household vacuum cleaner; (3) a small ejector which may either be purchased or improvised from a 1½ in. Y pipe fitting.

At one end of the rubber hose cut away, in the form of a long arc, the bottom and about half of the sidewalls to fit the radius of the commutator or ring to be ground. Cut a hole in the hose in the middle of the remaining arc portion to fit the grinding stone. Fit the hose to the stone and commutator or ring so as to form an enclosure or "shoe" around the grinding surface to collect the dust. Attach the other end of the hose to the intake of the ejector. Attach the vacuum bag to the exhaust of the ejector. Use compressed air from a common air line to produce the suction.

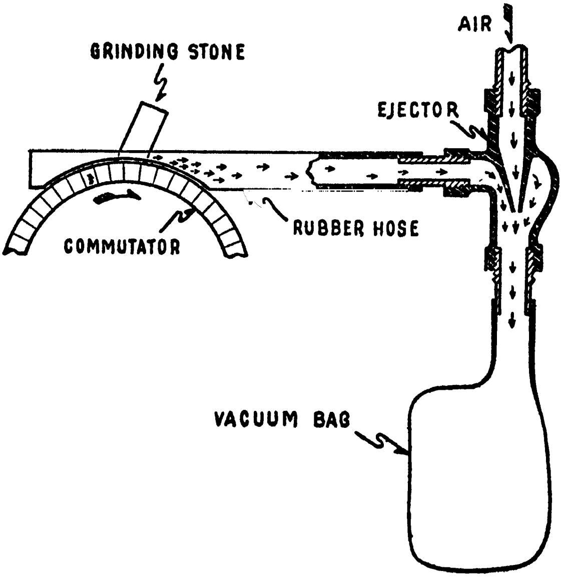


FIG. 78. Home-made dust collector.

**Solvents.** If the accumulation of dirt contains oil or grease, a solvent will usually be required to remove it. There are three types of solvents in general use for this purpose.

These are petroleum distillates, such as benzine or gasoline (not benzene or benzol, which are extremely toxic and should never be used), carbon tetrachloride, and a mixture of the two.

Benzine or gasoline has the least corrosive action on the insulation varnishes and for that reason—where conditions permit—are preferable to the other solvents.

Benzine having a flash point of 100° F. or higher, is perhaps the most generally desirable.

Solvents known commercially as "Stoddard Solvent" (described in U. S. Bureau of Standards as "Commercial Standard CS-3-28"), Cleaner's Naphtha, or Safety Type Solvents minimize the fire hazard and should be used in preference to gasoline or benzine, but ample precautions should nevertheless be used to prevent fires or explosions. When this type of solvent will not properly clean the apparatus a mixture of carbon tetrachloride and petroleum solvents may be used. A mixture of 50% carbon tetrachloride and 50% benzine, or 60% carbon tetrachloride and 40% gasoline is non-inflammable but the vapors mixed with the right proportions of air are explosive.

**Carbon tetrachloride.** In extreme cases it may be necessary to use straight carbon tetrachloride; however, its toxic effect must be considered.

This is a non-inflammable compound, but due to its mild and somewhat pleasant odor there is danger of working in excessively high concentrations. Since its vapor is heavier than air it may accumulate in pits and confined spaces. Even moderate exposures are very dangerous after drinking intoxicating liquors.

This solvent is much more corrosive in its action than the petroleum solvents. It evaporates quickly, however, and may be used for cleaning windings with mild risk, if reasonable precautions are taken.

**Applying solvents.** In cleaning electrical apparatus, solvents are generally used by wiping the insulation with cloths moistened with the cleaning fluid. In special cases, the solvents may be sprayed on the insulation, or the insulated parts may be dipped into the solvent.

**Caution: note carefully.** When petroleum distillates are used, guard carefully against fire and explosion.

Both benzine and gasoline are very inflammable and their vapors are extremely explosive when mixed with the proper percentage of air.

Be sure there is good ventilation and minimum fire risk.

If possible, do not let the workers' clothing become saturated with the solvent.

If the clothing should become saturated, it should be removed before leaving the work.

Always have fire extinguishers handy.

Keep metal tools from striking metal parts of the apparatus.

Workmen's shoes should not have protruding nails.

If using a hose to spray either cleaning solution or varnish, make sure that the nozzle is grounded.

When using carbon tetrachloride, workmen should be guarded against breathing the fumes and they should be under the close observation of some one familiar with artificial respiration.

Where the conditions are particularly bad, workmen located in pits or the holds of vessels should wear gas masks.

Adequate ventilation should be provided when any type of solvent is being used.

**Water, or water and solvents.** Electrical apparatus which has been filled with dirt, or has been submerged and is clogged with mud and foreign matter, will probably require a thorough washing out. In such cases, disassemble the apparatus and thoroughly wash all parts with water. Use an approved solvent to remove grease from the insulation. If water is applied to insulated parts with a hose, the pressure should not exceed 25 lb. per sq. in.

## DRYING

The matter of drying or removing moisture from insulation naturally follows cleaning. Here, too, we find prevention much better than the cure.

It may generally be assumed that insulation is moisture-free when the electrical apparatus is shipped by the manufacturer. However, surface moisture may accumulate during shipment and installation periods, and there is also likely to be some absorption of moisture from the atmosphere.

Experience indicates that new apparatus insulated for operation below 3300 v. may safely be placed in service without special drying, if a careful inspection of the windings does not disclose defects, dirt or moisture, and insulation tests are satisfactory. It is good practice, however, to operate such apparatus at lower than normal voltage for a short time, if it is practicable to do so.

The insulation of new apparatus wound for 3300 v. and higher service should be dried if a hot insulation resistance test shows a value below a safe minimum, which is usually accepted as one megohm for each 1000 v. of operating or rated voltage.

**Methods of drying.** There are three general methods of drying the insulation of windings: External heat, internal heat and a combination of external and internal heat. Where it is possible to have apparatus dried under vacuum while hot, this is, of course, an extremely effective process.

**Drying with external heat.** It is extremely important that the insulation of new electrical apparatus should be protected against moisture after the apparatus has arrived at its destination. The most satisfactory procedure is to maintain the insulated parts and the air immediately surrounding them at a temperature of 15° C. to 25° C. higher than the general air temperature of the room in which the apparatus is located, but not less than 40° C. actual temperature. This procedure will not only keep dry all insulation that is dry when the apparatus is received, but it will dry off surface moisture that may have accumulated during shipment of the equipment. If continued during the time generally required to erect large apparatus, such drying procedure will usually raise the insulation resistance from a value indicating extreme dampness to one entirely satisfactory for over potential tests or for placing the apparatus in service.

The method of producing and applying the heat will depend on many and widely varying conditions. Seldom will conditions be found ideal, and consequently the problem of drying may often require, on the part of the operator, a great deal of ingenuity and resourcefulness. Since much damage can be done by the misapplication of heat to the windings of electrical apparatus, it is of paramount importance that this type of work be entrusted to competent persons only.

The application of heat to the windings should in no way injure the insulation by overheating it, nor should it be applied so rapidly that internal vapor pressures will be developed sufficient to form pockets or to rupture the insulation. Furthermore, it is essential that adequate provision be made for the circulation of hot air within the apparatus being dried and that openings, for the escape of moisture-laden air and of gases, be made at the top of the enclosure.

**With steam heat.** Where low pressure steam is available, radiators or steam pipes placed below the end windings of a stator will provide safe and easily controlled heat. The enclosing parts should be set up against the frame or a temporary enclosure should be used. There should always be ventilating openings at the top of the machines to provide for the escape of moisture.

Where machines are equipped with water coil air coolers, low pressure steam may be circulated through these coolers to keep the insulation dry or to dry it.

**With forced air.** Hot air may be forced or blown through electrical apparatus to dry its insulation. The air may be heated by steam coils, in hot air furnaces, by electric heaters or by open fires. Although it will remove surface moisture quickly, generally this method is inefficient and costly, unless a blower and air duct have been provided for the permanent installation and there is ample space to locate a heating unit in the duct.

**With electric heaters.** External drying of the insulation of electrical rotating apparatus by electric heaters distributed under the end windings is strongly recommended. Space heaters are most convenient for this purpose. These heaters are only 3/16 in. thick, 1½ in. wide and from 12 in. to 43 in. long, depending upon their capacity. The cost of the heaters is low and their installation will cost very little. These heaters are sturdy, and have many applications; their salvage value is high.

**Heater capacity required.** The radiation factor of apparatus to be dried varies to such an extent with the type of apparatus and with the conditions under which the heaters are applied that it is impracticable to give definite data for use in calculating the heat required for a satisfactory drying temperature. The approximate kw. capacity of heaters required for drying the insulation of an enclosed type horizontal machine, such as a turbine generator or synchronous condenser, may be obtained by multiplying the total outside area of the end bells in square feet, by the desired degrees Centigrade rise and dividing by 1000. This assumes that space heaters will be suspended under the end-windings and that there will be small vents at the top of the frame.

The insulation resistance of high voltage armature windings depends almost entirely on the condition of the end-winding insulation. This insulation is not dried efficiently (and sometimes not safely) with internal heat, and when dried externally the punchings and other metal parts absorb a considerable part of the heat, making it still more difficult to calculate the heat required.

When drying the insulation of a large vertical machine that has not been subjected to unusual dampness, the temperature of the stator end-winding insulation will rise much more rapidly than the temperature of the stator punchings. Record both temperatures.

With space heaters suspended under the end-windings and the exhaust ventilation at the top of the machine, the temperature of the end-winding insulation should be slowly brought up to 85° C. and then maintained at that temperature until the insulation resistance has dropped to the minimum and then increased to a satisfactory value. This may be obtained before a temperature of 55° C. is indicated on the armature punchings.

**Oven heat.** A permanent drying oven is a good investment for a ship operating many small and medium-sized motors in damp locations.

A good temporary oven may be made of panels of heat insulating material secured to wood frames, or of sheet iron, brick, or concrete blocks lined with any of the many insulating materials.

Ovens should be ventilated to provide air circulation and to remove moisture. Some form of temperature indicating device should also be provided. Electric or steam heat is safest. Pre-heated air may be forced through the oven. Many types of heaters may be used if arrangements are made to eliminate fire risk and keep products of combustion out of the oven.

**Drying with internal heat.** The coil insulation of "wound" electrical apparatus may be dried by circulating current through the windings. Internal heat can be developed in this way without subjecting the insulation to voltages that might damage it during the drying operation. The procedure will depend upon the type of apparatus to be dried and on the facilities available for producing or applying the current.

There is always danger of serious injury to the windings when drying the insulation with current since the heat generated in the inner parts is not readily dissipated; furthermore, coils containing moisture are much more susceptible to injury from overheating than they are when thoroughly dry. Gases and vapor generated within the insulation by high temperature may develop such pressure that they are forced through the insulation, breaking the continuity of the layers or actually rupturing the material. This method should be followed only under competent supervision.

The drying should be continued until the insulation resistance has dropped to a minimum and has then increased until at least one megohm for each 1000 v. operating voltage is indicated, but in no case less than one megohm, regardless of voltage. It may then be desirable to maintain the temperature at from 15 to 25° above ambient until ready for operation.

**Drying alternating-current generators.** The short-circuit method means short-circuiting the armature windings and driving the generator, applying sufficient field excitation to give somewhat less than full load armature current. When the windings are provided with imbedded temperature detectors or when temperatures are determined by the increase of resistance method, the current may be adjusted to maintain an internal temperature of 85° C. from the beginning of the "dryout run." If the temperature indications are obtained by thermometers located on the outside of high voltage coil insulation, however, several hours may elapse before maximum temperature, under constant current, ventilation and ambient temperature conditions, are indicated; and since these temperatures may be from 2° C. to 25° C. lower than the temperatures at the inside of the insulation, it follows, therefore, that the temperature by thermometer should not exceed 65° C.

Low voltage from an external source may be applied to AC generator windings for drying coil insulation. The current must be controlled so as not to exceed full load current. The field poles of many AC generators are provided with damper windings. If the field does not rotate, or if it rotates at low speed these windings may overheat. Any excessive temperature necessitates a change in the drying operations. When alternating current is applied to the armature from an external source the field windings should always be short-circuited.

Low voltage direct current is seldom available for drying large AC generators. A slow drying temperature may usually be obtained by connecting the armature windings in series with the field winding and applying exciter voltage, if a separate exciter or bus excitation is available.

**Drying synchronous motors and condensers.** The short-circuit method is generally impracticable for drying synchronous motors and condensers. Low voltage from an external source may be applied with satisfactory results under the conditions described for AC generators, but it is seldom available where this type of apparatus is installed. External heat from electric heaters will be found more satisfactory.

**Drying synchronous converters.** If the converter can be driven from some external source, such as a separately belted motor, it may be dried by the short-circuit method, using the following procedure:

Raise the collector brushes; short circuit the armature on the direct-current side. Use a very weak field excitation. If the converter is shunt wound, low voltage separate excitation must be used; if compound wound, the armature may be short-circuited through the series field coils.

Synchronous converters are very sensitive when operated as series machines and there is danger of generating an excessive current which may result in damage to the machine and also personal injury. Consequently, this method of drying should not be undertaken except by the most experienced operators. Note the precautions listed under DC Generators, below.

When drying synchronous converters with current from a separate AC source, block the rotor so that it cannot turn. Raise the direct current brushes. Short-circuit the shunt field. Apply approximately 10% of normal alternating current voltage to the collector rings.

**Commutators** that are so wet that the insulation does not dry out when the winding insulation is dried will require special treatment.

If the front V ring is secured by bolts or studs, remove two that are diametrically opposite, if possible, and drain out any trapped water. In some constructions, the bolts cannot be removed, and it may be necessary to take off several nuts in order to get the water out and to admit hot air inside the assembly. When the front V ring is held in place by a nut or a threaded ring, the commutator should be securely banded before the V ring is loosened or removed.

The hot vacuum process is most satisfactory for drying commutators. Oven drying may be effective but it is slow. When conditions necessitate drying the commutator of a large machine without removing the armature from the field frame, this may be done by forcing hot air inside the commutator assembly or by applying low temperature electric heaters to the surface of the commutator. Extreme care and very close attention will be required for such operation. Commutators that were hot when submerged are likely to have water in the segment mica as well as in the bush and V rings.

**Drying direct-current generators.** The short-circuit method of drying is applicable to direct-current generators also.

In drying large DC machines, or rotary converters, by this method, it is advisable to operate them as shunt wound separately excited machines.

The series field should be taken out of circuit or reversed so that it becomes a differential series field winding.

On large compensated shunt wound machines it is often necessary to shift the brushes with rotation. This gives the machine an inherent drooping characteristic and tends to prevent the current from "creeping" up to dangerous values. In all cases an ammeter should be inserted in the armature circuit and the short circuit current kept within the nameplate value.

**Frequency converters.** If one machine of the set is in safe condition for operation, the machine to be dried may be driven as an AC generator and dried by the short-circuit method. When both machines require drying, arrangements may sometimes be made to use a belted motor to drive the unit with both machines short-circuited. In most cases, however, external heat from electric heaters will be found quite satisfactory.

Small and medium size AC or DC motors may be disassembled and dried satisfactorily in an oven.

Large individual motors are often dried in an improvised oven or "hot box" built around the motor and heated by electric grids or space heaters.

**Drying transformers.** In drying out transformers, there are at least four methods which may be used:

a) By internal heat.

b) By external heat.
c) By internal and external heat.
d) By heating in oil.

In general, method c) is recommended as the one most effective, as well as practical. Method d) requires much longer time.

Using external heat only, a large transformer may be placed in its own tank without oil and dried by blowing externally heated air into the tank at the bottom through the main oil valve. The top of the tank should be well ventilated. A small blower or fan should be used to get the proper circulation. It is necessary to force the heated air up through the ducts in the transformer windings. To accomplish this, baffles should be placed between the core and the case, closing off as much of the space as possible.

The best way to obtain the heated air is by blowing the air through grid resistors or around electric space heaters. The heaters should be placed in a fire-proof box. The temperature limits of the windings are from 80° C. to 90° C. measured by resistance. The temperature of the air entering from the heaters should not exceed 125° C. Measure the temperature of the windings by rise in resistance method frequently to make sure that the transformer is not overheated.

## INSULATION TESTING

**Methods and equipment.** In maintenance work, insulation tests are made to determine the condition rather than the quality of insulation. Tests that will indicate the presence of moisture, dirt or carbonized material without "breaking down" the insulation are, therefore, the most satisfactory maintenance tests. Accordingly, the service test most generally applied to electrical apparatus is the determination of the resistance of the insulation. Special conditions may justify dielectric tests, overpotential tests, high frequency tests or dielectric power-factor tests; and chemical tests, physical tests or other laboratory tests may be required to determine the cause of some unusual insulation failure.

## INSULATION RESISTANCE TESTS

These tests give an indication of the condition of insulation, particularly with regard to moisture and dirt. The actual value of the resistance varies greatly in different apparatus depending on the type, the size, the voltage rating, etc. The principal worth of such measurements, therefore, is in the relative values of insulation resistance of the same apparatus taken under similar conditions at various times.

High insulation resistance values do not assure high dielectric strength. Low insulation resistance, however, does indicate low dielectric strength. Insulation that is wrinkled or that has been seriously damaged mechanically may have a very high resistance but may fail at a relatively low dielectric test voltage. Also, two insulating materials in series, one of which has absorbed moisture and is in poor condition and the other dry and in good condition, will show an insulation resistance even slightly higher than for the good material. Surface dirt or moisture that causes low insulation resistance may also cause low dielectric strength.

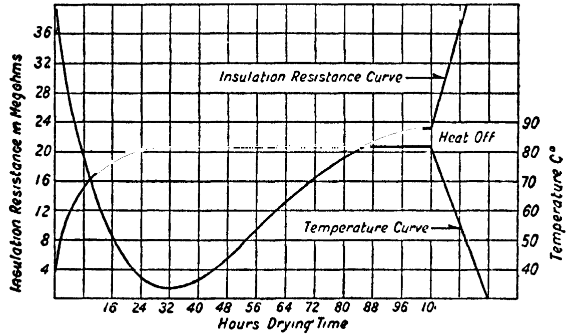


FIG. 79. Insulation drying curve.

Insulation resistance will generally vary greatly with temperature. It is important to note the machine temperature when taking insulation resistance measurements.

As an example, when new insulation, or insulation that is very damp, is being dried, the resistance will generally fall rapidly as the temperature is raised to a drying value. After falling to the minimum for a given temperature the resistance will rise as moisture is expelled from the insulation.

A representative insulation drying curve is shown in Fig. 79.

Measurements of insulation resistance are most readily obtained with a megger or an ohmmeter. For general maintenance work the megger should be of the 500-v. rating, although for special tests a 1000-v. or even a 2500-v. megger may be required.

When a 500-v. or 600-v. DC circuit is available satisfactory results may be secured with a DC voltmeter having high internal resistance. The method of measurement is first to read the voltage of the line, then to connect the resistance to be measured in series with the voltmeter and take a second reading.

**Resistance formula.** The measured resistance is then calculated by using the following formula:

$$R = \frac{r(V-v)}{v(1000000)}$$ In which:

$V$ = voltage of the line
$v$ = voltage reading with insulation in series with voltmeter
$r$ = resistance of voltmeter in ohms (generally marked on label inside the instrument cover)
$R$ = resistance of insulation in megohm (1,000,000 ohms)

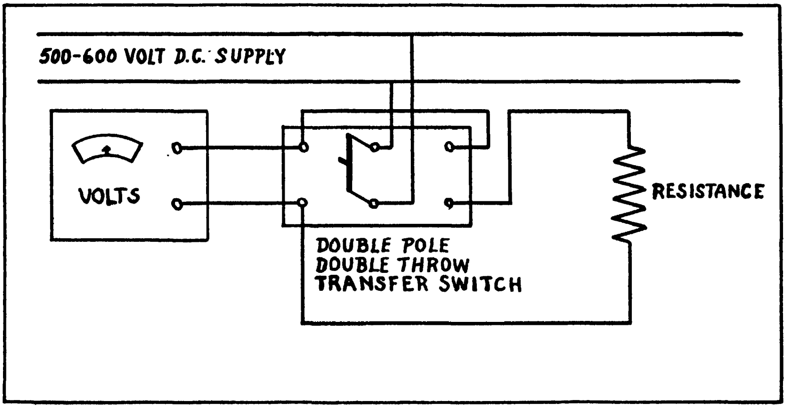


FIG. 80. Connection for measuring insulation resistance.

The method of connecting the apparatus is shown in the diagram, Fig. 80.

If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of the apparatus to be measured, and the voltmeter between the windings and the other side of the circuit.

Voltmeters having a resistance of one megohm are now made for taking insulation resistance measurements. If one of these instruments is used, the calculation is somewhat simplified since $r = 1$ and the above formula becomes:

$$R = \frac{V}{\ } - 1$$

**Example:** In testing a generator insulated for 13800 v. service with a line voltage "V" of 600; using a voltmeter having an internal resistance "r" of 1000000 ohms (one megohm); assume the voltage "v" indication with the meter in series with the insulation to be 40:

$$\text{Then: The resistance} = \frac{1000000(600 - 40)}{40 \times 1000000} \text{ or } R = 14 \text{ megohms.}$$

$$\text{Or, as this is a megohm meter: } R = \frac{600}{40} - 1 \text{ or } R = 14 \text{ megohms}$$

A safe general rule is that the insulation resistance should be approximately 1 megohm for each 1000 v. of operating voltage with a minimum value of 1 megohm.

No new apparatus should have an insulation resistance of less than 1 megohm.

Insulation resistance of apparatus in service should be checked periodically at approximately the same temperature and under similar conditions of humidity to determine possible deterioration of the insulation. When such measurements made at regular intervals as a part of the general maintenance routine show wide variations in insulation resistance, the cause should be determined and abnormal conditions should be corrected before an insulation failure occurs.

**Dielectric tests.** The purpose of dielectric tests is to determine that insulation will withstand voltage stresses occurring during normal or assumed abnormal conditions of operation.

The assurance provided by a dielectric test may warrant the risk involved in applying it as "preventive maintenance" prior to a critical period of operation. The damage resulting from an insulation failure at the time of a properly applied dielectric, or high voltage, test is likely to be very little compared to the loss caused by a break-down while apparatus is carrying an important load.

The insulation of electrical apparatus that has been repaired or reconstructed should be given a dielectric test.

Samples of insulating oil taken from transformers, induction regulators and circuit breakers at regular intervals should be tested for breakdown value.

Dielectric tests are a part of the regular test procedure of manufacturers of electrical apparatus. The Standards of the American Institute of Electrical Engineers are the accepted authority for these tests.

The A.I.E.E. Standard applying to Direct Current Rotating Machines (No. 5), Alternators, Synchronous Motors and Synchronous Machines in general (No. 7), Synchronous Converters (No. 8), Induction Motors and Induction Machines in general (No. 9), Direct and Alternating Current

Fractional Horsepower Motors (No. 10) and Transformers, Induction Regulators and Reactors (No. 13) all specify a dielectric test (for the main winding insulation of new apparatus) of twice the rated voltage of the apparatus plus 1000 v.

The authorized dielectric test for field windings is 10 times the exciter voltage, but in no case less than 1500 v.

Each A.I.E.E. Standard lists exceptions. If special conditions exist, reference should be made to the Standard that applies to the apparatus involved.

Dielectric tests are generally made with alternating current of commercial frequency (25-60 cycles) for a period of 60 sec.

Direct current high voltage tests are being applied to a limited extent in testing insulation. Their principal use is for determining the dielectric characteristics of cables and for laboratory work.

A 3 Kva. 30,000 v. portable testing outfit has been especially developed for testing winding insulation and transformers and circuit breaker oil. When larger apparatus will be tested an outfit of greater capacity will be required.

**Over potential tests.** In operating and maintenance organizations this designation generally signifies tests made to determine if there is adequate insulation between the turns or conductors of a coil or between adjacent coils in a winding. That is, they are called "short-circuit tests," whereas dielectric tests are called "ground tests." Such an over-potential test is made by over exciting the field of a rotating machine operating as a generator with the armature not connected to the line, or by raising the voltage applied to one winding of a transformer with the other winding open. Usually a higher frequency circuit will be used in making this test on a transformer. Extreme caution should be exercised in applying these tests as there is danger of seriously damaging the apparatus—not only the windings, but also the "iron." Provision should be made to open the field circuit of the generator, or the supply circuit to the transformer, very quickly if a short-circuit develops.

**Induced voltage tests.** These tests, as generally made, are applied to detect short-circuits in coils or short-circuits or incorrect connections in wound armatures. They are made with an AC magnet, and are the "growler" tests known to all armature winders.

**High frequency voltage tests.** These tests, which are described in detail in Mr. J. L. Rylander's A.I.E.E. paper of February, 1926, are particularly valuable in detecting insulation faults between various parts of a coil or winding. They are applied during various processes in the manufacture of electrical apparatus, but because of the rather complicated and expensive equipment required they are not recommended as maintenance tests.

**Dielectric power factor tests.** In general the power factor test shows the same type of losses as the insulation resistance test, but with the addition that it is more sensitive and more comprehensive. With the AC loss measurement, as indicated by the power factor, the losses in the poor part as well as those in the good part of the circuit are shown. As these tests require rather intricate and costly equipment, they are seldom made in maintenance work except in testing high voltage transformer and circuit-breaker bushings.

**Physical tests.** Various methods and devices have been developed to determine whether insulation will withstand shock or vibration, particularly after having been subjected to prolonged high temperature operation. While such tests frequently have a direct bearing on maintenance problems, they are generally in the nature of research work and for that reason are not treated here.

**Chemical tests.** These tests are regular requirements for insulating oils. Solids, liquids and gases coming in contact with insulation may also require chemical analysis. There are many others that may sometimes be required in maintenance work. These include Specific Gravity Tests and Viscosity Tests for varnishes; Drop Tests and Ball and Ring Tests for gums, and Flash and Fire Tests for oils. Then there are tests—so many that even a list would be formidable—that must be made by laboratory or research engineers.

Every electrical maintenance man should, however, make it a point to make frequent checks of the specific gravity of the insulating varnishes he is using to treat electrical apparatus. This is important if the best results are to be obtained from varnish treatments.

The ultimate purpose of all insulation tests is to insure satisfactory service from electrical apparatus. Therefore they all affect maintenance.

## THE DIRECT-CURRENT MOTOR

**Cleanliness.** The importance of keeping electrical equipment clean and dry is always worth stressing. Particularly is this true of the DC motor, with its commutator, brushes and brush rigging.

Suitable precautions must be taken to protect the motor from the effects of oil, dust, grease, moisture and corrosive gases. Commutators and brushes cannot give good performance when exposed to adverse conditions of this kind.

Tools, bolts, oil cans, etc. must not be allowed to lie around the motor or on its frame.

Keep the motor free from dust by the occasional use of compressed air or hand bellows. Care should be taken to see that the compressed air lines are free from moisture.

**Insulation.** The general subject of insulation is treated in detail in a separate section. No special information for DC motors as a class is required here.

**The armature.** The armature is the heart of the DC motor. Through it flows the main line current, and, if the machine is overloaded, the armature is the first to give evidence of distress. If given reasonable attention from the standpoint of inspection and cleaning, it should—under normal operating conditions—give little or no trouble.

If it does give trouble, the repair should be entrusted only to a competent person.

In handling, observe the following points:

1) Don't roll the armature about the floor. A coil may be injured; a band may be nicked.

2) Support or lift the armature only by its shaft, if possible. Otherwise, use a wide lifting belt under the core.

3) Never allow its weight to rest on the commutator or coils.

**Preserving the winding.** Periodic varnish and baking treatments will prolong the life of the winding. First, however, clean the winding thoroughly with a solvent solution to remove grease and other dirt, and then:

1) Inspect coil bands, replacing any that are loose.

2) Pre-heat armature in an oven at from 85° to 100° C.

3) Keep the varnish at the viscosity recommended by the varnish manufacturer.

4) Immerse the armature endwise—commutator end up. Allow to drain well before baking.

5) Bake also on end; this will avoid varnish piling up on one side, which may result in an out-of-balance condition when put into operation.

The baking time and temperature should be in line with the varnish manufacturer's recommendation. The average is usually from 8 to 12 hrs. at 100° C.

Repeat with successive treatments if the machine is operating under severe conditions of acid fumes, oil or moisture.

**Keep winding tight.** Periodic treatments as above are desirable, even though the equipment is not subject to adverse atmospheric conditions. A winding will dry out and loosen in operation. Loose windings fail rapidly when subject to centrifugal stresses and vibration.

Varnish treatments will fill the pores and crevices, put flexibility in the insulation and hold the coils solidly in the slots.

A new armature winding will deteriorate rapidly unless the coils fit snugly and are held rigidly in place during operation. When winding crane or railway type armatures it is common practice to preheat the wound core, install temporary bands, before the varnish and oven-treatment. These temporary bands are then replaced with permanent bands. This procedure will insure the coils being pulled firmly into final position in the slots while the insulation is warm and flexible.

**Banding.** Insofar as possible duplicate the banding originally furnished by the manufacturer, that is, change neither the material in the banding wire, the diameter of the banding wire, nor the width or position of the band. Increasing the band width may cause heavy currents in the bands, sufficient to overheat and melt the solder.

If larger or heavier banding is required, it may be desirable to sectionalize, i.e., install 2 or more bands separated and insulated from each other. Very high speed conditions may call for double banding, that is, one on top of the other.

**The commutator.** Since the commutator may assume an out-of-round condition after even treatment, it should be trued and polished in a lathe as a final operation. However, first examine it for any sign of looseness.

If the commutator bars are tight they will give out a clear bell-like-ring when tapped lightly with a small hammer. If the commutator does not ring, but instead sounds flat when struck, pressure should be put on the front "V" with a screw press, tightening the front "V" ring bolts as required.

**Mica "V" ring.** The exposed portion of the front mica "V" ring is normally the target for moisture, oil and dirt, which frequently cause flash-overs and break-downs to ground.

This section is usually protected with a layer of twine, covered with a layer of surgical tape sewed fast with linen thread.

A very effective protection is obtained by the following procedure:

1) Clean exposed mica thoroughly and brush with shellac.

2) Wind a layer of small torpedo twine, brush with shellac and iron smooth with a hot iron.

3) Paint with approved cement prior to giving the armature its oven treatment, and allow to bake.

4) Apply a second coat prior to the second baking treatment of the armature.

5) Finish with a third coat as a final operation and allow to air dry.

The result will be a very smooth finish, which will readily shed carbon dust and oil, and give maximum protection to the mica.

**Brush shunt corrosion.** This is sometimes a problem on vessels where battery fumes are present.

Cotton stockinette sleeving provides a splendid protection against corrosion and shunts dipped in melted vaseline or red commutator cement have also effectively resisted this corrosion.

**Field windings.** Do not conclude that a field winding is defective until you have carefully inspected rheostats, switches, and other devices in the motor circuit.

Connections and leads should be examined and tested to determine that they are electrically and mechanically satisfactory. If the series field winding of a compound-wound motor is connected in the reverse direction, the motor will either fail to start, or perhaps run in the opposite direction, with a weak torque, but in any case the operation will be unsatisfactory, and sparking at the commutator will probably be noted.

If the field winding of any type of DC motor is open circuited, the motor will fail to start or it will operate at excessive speeds at light loads, and serious sparking will occur at the commutator.

**Field coil heating.** Heating of field coils may develop from any of the following causes:

1) Speed too low.
2) Voltage too high.
3) Forward or backward lead of the brushes too great.
4) Partial short-circuit of one coil.
5) Overload.

Faulty performance manifested by poor commutation, improper speed, and overheating of the armature is frequently traceable to defective field windings or improperly connected field coils. If the field circuit is free of grounds and a shorted shunt field coil is suspected, comparative resistance measurements should be made of the individual coils and compared with the resistance of a similar coil which is known to be in good condition. Such a comparative check should be made preferably when the field windings are hot or are near normal operating temperature.

The shunt field coil is made of a large number of turns of relatively small size conductor and a coil which may show the correct copper resistance value when cold may show a lower value when heated. This is due to defective insulation between turns on adjacent conductors, which may not actually produce short circuits until expansion has occurred with increased temperature.

If the correct resistance value of a good coil is not known, comparative checks with either a Wheatstone Bridge or by the voltmeter-ammeter method will usually provide a reliable indication as to the condition of the coils. If neither a Bridge nor an ammeter is available, a clue as to the condition of the coils can be obtained by connecting all shunt coils in series to a source of constant potential and measuring the voltage drop across the individual coils.

**Replacing field coils.** In removing a shunt or a series field coil, disconnect the coil from the adjacent coils and remove the bolts which secure the pole-pieces to the frame. This will make it possible to remove the pole-piece and coil, after which a new pole-piece with its coil can be installed. Care should be taken in replacing the pole with the coil, to be sure that the same steel liners between the frame and the back of the pole are replaced to insure an even air gap of the original machine; in reconnecting the coil, place it so as to obtain the proper polarity of the coil.

A very simple means of testing the polarity is by means of a compass, a needle or a piece of steel wire suspended from the middle by a string. The polarity should be alternately north and south around the frame. Bring the polarity needle within the magnetic field of any pole. One end of the needle will point towards this pole and this end should be repelled by the next pole and so on around the frame. If this reversal of the needle does not occur there is a wrong connection of the field coil.

**Locating brush position.** A new machine from the factory has its brush position determined on the test floor, by means of determining the electrical neutral, and it should not be necessary to alter it. If, for any reason, it is suspected that this may have been changed, the manufacturer's instruction book gives full instructions for determining neutral by various methods. The method most commonly used, namely the "kick" method, is outlined here.

With all the brushes raised from the commutator and the machine standing still, if the shunt field be excited to about ½ its normal strength and the field current suddenly broken, voltages will be induced in the armature by transformer action. It will be found that the induced voltages in conductors located at equal distances to the right and left of the main pole centers will be equal in magnitude and opposite in direction.

Hence if the terminals of a low reading voltmeter (5 v.) are connected to 2 commutator bars on the opposite side of a main pole, and exactly half way between the center lines of 2 main poles, the voltmeter will show no deflection when the field current is broken. The spacing of these commutator bars is, therefore, the correct distance between brushes on adjacent brush arms.

The most practical method of making this check is to make 2 pilot brushes of wood or fibre to fit the regular brushholder, each brush carrying in its center a piece of copper fitted for line contact with the commutator, and with the lead for connection to the voltmeter. By fitting 2 such pilot brushes in the holders of adjacent brush arms the brush rigging may then be shifted slightly forward or backward, as necessary, until breaking the field current produces no deflection on the voltmeter.

By noting the position at which no deflection is obtained for each pair of brush arms, the average of the positions of neutral thus obtained gives the correct running location for the brushes.

Another quick and convenient method of locating neutral on a DC motor having shunt fields is to check the speed of the motor in either direction with the same impressed line voltage. The position of the brushes, which produce the same speed in either direction under the same voltage conditions, is the correct neutral.

**Bearings.** The bearings of all electrical equipment should be subjected to careful inspection at scheduled periodic intervals in order to secure maximum life. The frequency of inspection, including addition of oil, changing the oil, and bearing wear is best determined by a study of the particular operating conditions.

The newer type of sealed sleeve bearings require very little attention since the oil does not become contaminated and oil leakage is negligible. Maintenance of the correct oil level is frequently the only upkeep required for years of service with this type of bearing.

Older types of sleeve bearings require a great deal more frequent inspection and checking for wear, and oil changes should be made more often.

Safe temperature rise for a bearing is considered to be 40° C. rise above the room ambient. At this temperature a bearing feels only comfortably warm to the bare hand.

When electrical equipment has to operate under extreme differences in air temperatures (very hot or very cold) a lighter oil may be found desirable during the cold weather.

Care should always be exercised in the use of reclaimed lubricating oils. The filtering operation should be positive and remove all foreign and injurious matter.

A warm bearing or a "hot box" is probably due to one of the following causes:

No oil
Failure of the oil rings to revolve with the shaft
Rough bearing surface
Improper fitting of the journal boxes
Bent shaft

A poor grade of oil, or dirty oil

Bearing may be too close a fit

End thrust, due to improper leveling. A bearing may become warm because of excessive pressure exerted by the shoulder of the shaft against the side of the bearing

End thrust, due to magnetic pull, rotating part being "sucked" into the field because it extends beyond the field poles further at one end than at the other

Excessive side pull, because the rotating part is out of center

If the bearing becomes hot, first reduce the load if possible and feed lubricants freely, loosening the nuts on the bearing cap, and if the machine is belt connected, slacken the belt. If relief is not afforded, shut down, keeping the machine running slowly until the shaft is cool, in order that the bearing may not "freeze." Renew the oil supply before starting again.

A new machine should always be run unloaded or at slow speed for an hour or so in order to see that it operates properly. The bearings should be carefully watched to observe that the oil rings are revolving and carry a plentiful supply of oil to the shaft.

Information concerning sealed-sleeve, ball, roller, thrust and other types of bearings is given in another section later on, "Bearings and Lubrication."

## COMMUTATOR MAINTENANCE

The most important factor and the one upon which the success or failure of any direct current machine depends is commutation. Regardless of any other good features a machine may have, it is of no commercial importance unless it can be made to commutate successfully.

Assuming that the design of a machine is such that good commutation is to be expected, one of the surest means of securing continued satisfactory operation is through maintaining the surface of the commutator in good operating condition. In general, this means that the commutator surface should be smooth, concentric, and properly undercut.

**Causes of poor commutation.** In power and industrial work, commutators may become rough through overloading, which produces excessive sparking or burning, and overheating. Further, over any considerable period of time, any of the above abnormal conditions may exist more or less frequently, depending on the severity of the service, and as a poor surface becomes cumulatively worse, a point is reached where more satisfactory operation, and less frequent brush replacement, can be obtained by placing the surface in first class condition.

Commutator roughness is usually characterized by an abrupt change from one bar to the next as distinguished from an eccentric commutator in which there is a very gradual change in the surface where the commutator might be said to be egg-shaped. Variations from one bar to the next of as much as 1/10,000 in. are sufficient to cause a commutator to perform badly, break brushes or cause excessive brush wear on high speed commutators.

Roughness of a commutator surface can be detected by placing a pencil on a brush while the machine is rotating. Care should be taken to stand on a board or insulating platform of some kind, not to touch any metal part of the machine, and to use a wooden pencil if the machine has voltage on it. The surface of a commutator should be concentric within 1/1000 in. on commutators whose peripheral speeds are around 5500 ft. per min. For peripheral speeds in the neighborhood of 9000 ft. per min., commutators should be concentric to within .05/1000, which is about the practical limit for grinding.

Slow speed, large diameter commutators will operate successfully with greater eccentricity than mentioned above because the angular velocity is low and the brushes can follow the surface, but it is poor practice to operate even very slow speed commutators with an eccentricity greater than 3/1000 as this may be enough to cause side wear of the brushes. The concentricity of a commutator can be checked with a dial gauge mounted on a brush.

**Grinding.** Resurfacing of a commutator should always be done with a grinding rig, whether it is to be ground concentric or in order to remove high bars or flat spots. A hand stone should never be used on a commutator to obtain a true surface, because it simply follows the irregularities in the surface and in some cases may even exaggerate them. The grinding rig consists of an abrasive stone set up similar to a lathe tool in a rigging or carriage which may be moved back and forth in an axial direction and equipped with a radial feed. (See Fig. 81.) It should be supported very rigidly so that the stone is subjected to a very minimum of vibration. In large DC equipment, such a rigging can be mounted on a brush arm by removing the brushholders on that arm. In some cases, it may even be desirable to brace the brush-holder bracket arm, while grinding, to obtain maximum rigidity. It is also possible by removing the brush rigging to support the grinder on parallels supported from the bedplate.

Grinding should be done when the machine is running in its own bearings and at rated speed in the case of a constant speed machine. If grinding is done at low speed, any slight unbalance will cause the commutator to run eccentric at rated speed.

Great care must be exercised to prevent copper and stone dust from entering the windings. The grinding rig should be equipped with a vacuum cleaner arrangement, fitted over the stone to catch all dust. (See page 189.) If a suction system is not available, the necks of the commutator and the front end windings should be protected by pasting heavy paper over them or by covering with a cloth hood properly applied.

FIG. 81. Grinding device for truing commutators.

In order to rotate the machine, it may be belted to an auxiliary driving motor or in the case of an M.G. Set, it can be run from the machine on opposite end of shaft, if there is not sufficient space available. The armature must be removed from the frame Since the bearing housings are an integral part of the frame, it is difficult to rotate the armature without considerable investment in tools and fixtures. Again railway motors may be of two different types as regards bearings—that is, sleeve bearing or anti-friction (ball or roller) bearings. Practically all railway motors having sleeve bearings are relatively slow speed machines and as such commutator reconditioning can be done satisfactorily in a good lathe by taking a very fine cut off the surface and then polishing with a rotating wheel similar to the procedure used in turning and grinding shafts.

With ball or roller bearing motors, the speeds are quite high and it is ordinarily not satisfactory to do commutator grinding work in a lathe.

This work should be done in a special rigging equipped with a grinding rig as described above, a small auxiliary driving motor, and an arrangement of adapters for the bearings so that the armature can be run in its own bearings. The grinding should be done at a speed as near to rated maximum speed as possible and still have the grinding stone not affected by vibration. If it is impossible to grind an armature in its own bearings, a satisfactory grinding may be obtained in a lathe if the inside races of the bearings are made to run absolutely true in shaft centers. This is accomplished by scraping the shaft centers until the bearing races run true. This latter method is not to be recommended except as an expedient in cases of emergency.

The stones used in grinding commutators might be classed as rough, medium and fine. The rough stone has a grit of about 80 mesh and is used only where a very large amount of copper is to be removed. It should be used very seldom because if sufficient copper is to be removed to warrant its use, it would be better to take a cut off the surface in a lathe. The medium stone has a grit of about 120 mesh and is used for the bulk of the grinding work, the fine stone being used only to obtain a fine finish. The fine stone should have a grit of about 200 mesh.

After grinding, all commutator slots should be cleaned out thoroughly and the edges of the bars beveled. This beveling accomplishes two things; it removes the burrs caused by the stone dragging copper over the slots, and eliminates the sharp edge at the entering side of the bar under a brush. The bevel on the bars is done with a special beveling tool and should be about 1/32 chamfer at 45°, for medium thickness of bars. For thinner or wider bars, the beveling can be changed accordingly.

Practically all up to date machines have undercut mica. This undercutting should be kept 1/16 in. deep ± 1/64 in. If it is apparent that enough copper is going to be removed by grinding so that the undercutting will be shallow, the commutator should be reundercut before grinding. This is done by means of a small circular high speed saw about .003 in. thicker than the nominal thickness of the mica. In undercutting, great care must be taken to see that a thin sliver of mica is not left against one side of the slot. Sometimes this sliver must be removed by scraping by hand. Fig. 82 shows hand tools for this purpose.

After grinding, undercutting the mica, and beveling the edges of the bars, the commutator surface should be polished, while operating at rated speed. Aloxite or sandpaper should first be used (never emery cloth or paper) as this will remove the burrs due to beveling. After a very fine grade of sandpaper is used, a high polish can be used by burnishing the commutator with dense felt or canvas. A further improvement of the surface can even be secured if a small amount of light oil is applied to the canvas during the polishing.

**Commutator seasoning.** Some years ago it was practically taken for granted that a certain amount of commutator seasoning would take place in the field during the first year of operation and that commutators should be tightened periodically as the mica baked out. Factory methods and equipment have been greatly improved, so that almost all commutators are now shipped thoroughly seasoned and it is no longer necessary to tighten them in the field.

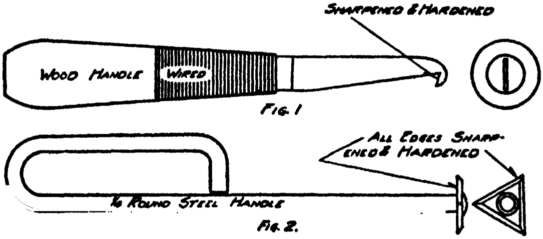


FIG. 82. Two hand tools used for undercutting.

## OTHER CAUSES OF POOR COMMUTATION

In addition to keeping the commutator surface in good condition, there are a number of other points which should be checked if trouble due to poor commutation is encountered:

**Mechanical spacing of poles and brushes.** Due to assembling and reassembling, or due to rough handling of machines, it is possible for pole and brush spacing to be out of adjustment. Main and commutating pole spacing must be uniform within ± 1/32 in. Also, the horizontal axis of each pole piece should be parallel to the shaft of the machine. Adjustments of pole pieces can be made by means of clearance holes in the frame for pole bolts. Brush-holder spacing must also be uniform around the commutator within ± 1/32 in. This can be checked by passing a tape around the commutator and marking the position of one brush in each arm.

The position of other brush-holders on the same arm can then be adjusted so that all brushes are perfectly aligned in an axial direction. Brush-holders should also be adjusted so that there is about ⅛ in. maximum clearance between brush boxes and the commutator. This clearance will increase as the commutator wears and should be taken up by moving the brush-holders down correspondingly.

**Staggering brushes.** Brushholder arms should be staggered in pairs in an axial direction approximately ⅜ in. to prevent grooving of the commutator. DC brushholders should be adjusted so that the pressure on all brushes is as uniform as possible. This prevents selective action by which certain brushes may take more or less than their proper share of the load. The pressures used vary considerably with the grade of brush and the type of service, and should be obtained from the instruction book covering the type of generator or motor. Brushes should also be checked frequently to make sure that they move freely in the holders. Any brushes found sticking can be freed by sanding the high spots with fine sandpaper. Fig. 83 illustrates staggered brushes.

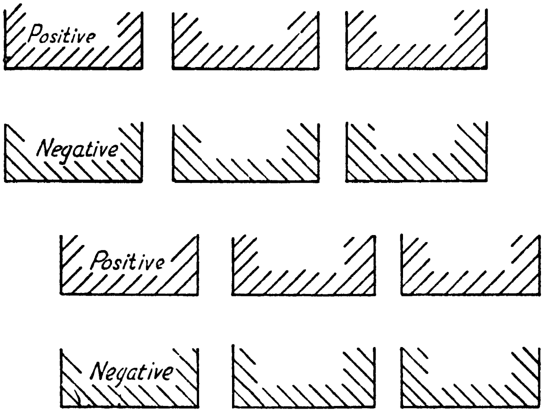


Fig. 83. Staggered brushes.

**Neutral determination.** Location of the correct brush position is covered on page 206.

## STARTING AND SPEED REGULATING RHEOSTATS FOR DC MOTORS

**General.** Rheostats are used for starting and speed regulation of series, shunt and compound wound motors in non-reversing service for the operation of fans, blowers, pumps, machine tools and similar direct current motor applications, ranging from ¼ to 150 HP.

**Cleaning.** To keep rheostats in good operating condition, periodic inspection plus cleaning and smoothing the contacts with sand-paper is usually all that is needed. The low up-keep cost of rheostats is due to such features as magnetic blowout devices, high contact pressures, contacts raised above the face plate, rugged moving parts and easy accessibility. However, some arcing and burning of contact making parts is unavoidable and dressing with a file may be required occasionally. Contacts should always be smooth. After each treatment with file or sand-paper (emery cloth should NOT be used) all parts should be thoroughly cleaned, including surfaces between contacts, and contacts should be very lightly greased. Sometimes cutting of the metal is caused by sharp contact edges, or by abrasive matter in the air. If the latter, greasing should be omitted.

**Reversing contacts.** Most types of rheostats have movable and stationary contacts which can be turned over and used on the other side. This gives the contacts double life, but turning over should be done only when abnormal burning and subsequent dressing with a file has made adjacent contact surfaces uneven. The moving contact must bridge and be in firm contact with each adjacent stationary contact. If these points are not checked, irregular increments in speeds or voltage will be the result. On larger type of rheostats or those with movable contact of the compensated type a slight variation between contact surfaces will not impair operation. It is generally found advisable when turning over one contact to turn all others at the same time. Oxides form on unused copper surfaces. This film should be removed with fine sand-paper and surfaces cleaned before placing rheostat in service.

**Spring tension.** Firm pressure between contacts should be maintained by proper spring tension to minimize pitting, heating and oxidation which aggravates abnormal conditions. The recommended moving contact spring pressure for each type of rheostat may be checked with a hook spring balance, measuring the pull in pounds necessary to separate the contacts. In most cases this is impractical. The desired limit on spring adjustments is to provide a pressure not great enough to injure the surface of either moving or stationary contacts, nor to set up a frictional force preventing resetting of arm on rheostats of the low voltage release type. The turns of the spring should not touch when compressed. Weak springs should be discarded.

**Resistor replacement.** Abnormal starting or operating conditions may burn out a section of the rheostat resistor. In this case, the face plate, together with the resistors, can easily be removed from the box and the damaged units repaired or replaced. If the resistor is of the wire wound Bobbin type, covered with a cement coating, a complete new set is recommended; if it is a suspension grid type, the burned out section should be replaced with one of the same pattern or style number; if it is an edge-wound strap resistor, the break may be bridged with a clamp similar to the type furnished with the resistor. In most types of rheostats, the field resistors are removable from the resistor mounting without disconnecting the wiring.

**Magnet coil.** Practically all starting rheostats of low horsepower rating have a magnet coil as part of the low voltage release. This coil is connected directly across the line. The release is adjusted to hold the operating handle in the last running position as long as the voltage is normal.

If it is desired to hold the starter in at slightly less than normal voltage, the holding power of the coil can be increased by filing down the little brass pin on the moving arm. However, this method should not be carried too far, nor should the operating arm be held in the running position by force. It is more economical to install a new magnet coil or spring than to take a chance on harming the motor by excessive starting current.

The rheostat should not be used to stop the motor. A safety switch or circuit breaker is provided for this purpose.

**Checking loose connections.** After a rheostat has been installed and in operation, all connections should be checked at least twice to make sure they remain tight when subject to heating. Loose connections are a considerable source of trouble causing many delays and they are difficult to find unless burning or failure of some other device occurs. Means of checking are limited and in most cases restricted to mechanical inspection. This should be done periodically. One of the best devices for checking rheostats is an Ohm-meter. It is convenient, rugged in construction and small in size. Ohmic values are indicated on the dial. With this instrument and a record of normal resistance value, any change between two rheostat points can be determined readily. From the readings it will be obvious if the circuit is normal or not. Incidentally, burned out resistor tubes can be traced quickly in this manner.

See pages 81–97 for illustrations and diagrams of various rheostats and controllers.

## THE AC INDUCTION MOTOR

The maintenance of the AC Induction Motor may be grouped under the following headings:

Stator windings, Rotor windings, Brushes and collector rings, and Bearings.

The subject of Brushes, Current Collectors and Commutation is an important one and is treated separately. Likewise, Bearings and Lubrication is a subject associated with all types of rotating machinery and manufacturer's instructions must be carefully followed.

Two types, the squirrel cage rotor and the wound rotor construction have become the standard alternating current motors. The characteristic features of stationary primary element, distributed windings and small air-gap are common to both types. The squirrel cage motor has no external rotating or secondary connections. The secondary of the wound rotor motor may be connected through slip rings to an adjustable secondary resistance.

The modern induction motor, particularly the squirrel cage type, is probably the most rugged rotating electrical apparatus ever developed. Maintenance requirements, outages and repair costs, therefore, depend to a very great extent on the correctness of the application. However, the first principle of electrical maintenance—**keep the apparatus clean and dry**—is fundamental. This implies periodic inspections, which are a very desirable check on operating conditions.

Before discussing those details dealing primarily with maintenance, it is well to understand a few of the fundamental characteristics of the induction motor, which we shall briefly comment on here:

**Slip.** At no load an induction motor runs at practically synchronous speed; with a load, the motor is below synchronous speed by a percentage known as the slip, that is, if the synchronous speed is 1800 r.p.m. and the full load speed 1700 r.p.m., the slip at full load is 5½%. The slip of any induction motor depends on the voltage drop in the secondary circuit, i.e., on the secondary resistance x current.[2] The greater the secondary resistance, the higher is the starting torque with a given current; the greater the slip, the greater also are the losses, and the lower the efficiency.

**Torque.** There are two kinds of torque that must be considered in a motor—the starting torque and the pullout torque. Motor torque must be balanced against efficiency and power factor. Excessive starting torque results in low efficiency, low power factor and poor speed regulation; while on the other hand, if the starting torque is too low, the load cannot be started in many cases. Very high pullout or stalling torque also means low power factor with high starting current; while if the pullout torque is too low, the motor may stall on ordinary harmless overloads. *A stalled motor may result in "roasted" insulation.*

**Voltage and frequency.** For best results, induction motors should be operated at their normal voltage and frequency. Some variations from normal voltage and frequency is allowable, the voltage limits being approximately 10% from normal and the frequency limits not exceeding 5%. The voltage and frequency should never be varied simultaneously in opposite directions, and both should not be varied at the same time to the extreme limits given. With any variation of either the voltage or the frequency from normal conditions, the following changes from normal operating characteristics must be expected:

| Power Factor | Torque | Slip | Full Load Eff. |
|---|---|---|---|
| Voltage high—decreased | increased | decreased | approx. same |
| Voltage low—increased | decreased | increased | approx. same |
| Frequency high—increased | decreased | same | approx. same |
| Frequency low—decreased | increased | same | approx. same |

In general, any change from normal frequency should be accompanied by a change of voltage proportional to the square root of the frequency. For example, a 400 v., 60 cycle motor on 66⅔ cycles will give very nearly normal operating characteristics if the voltage is made,

$$\sqrt{\frac{66\frac{2}{3}}{60}} \times 400 = 422$$

For decreased frequency, however, it is not recommended that motor be operated on less than normal voltage on account of increased current and temperature. The application of the foregoing rule for higher than normal frequency gives reduced temperature rise.

**Insulation.** The useful life of an induction motor depends largely upon the condition of its insulation. Insulation should be suitable for the operating requirements. (See sections on Materials and Applications; Cleaning and Drying; and Testing.)

## MAINTENANCE OF STATOR WINDINGS

The stator winding appears to be so simple and rugged as to cause one to frequently overlook the necessity for certain maintenance procedure. However, a glance into the average motor repair shop will make it apparent that the induction motor stator is after all a vulnerable piece of equipment. Most of the work going on will be replacing or repairing stator windings.

Stator troubles can usually be traced to one of the following causes:

Worn bearings, Moisture, Overloading, Operating single phase and poor insulation.

Dust and dirt are usually contributing factors, some forms of dust being highly conductive and contribute materially to insulation breakdowns. The effect of dust on the motor temperature through restriction of ventilation is another reason for keeping the machine clean, either by periodically blowing out with compressed air or by dismantling and cleaning. The compressed air must be dry and throttled down to a low pressure which will not damage the insulation.

**Moisture.** One of the most subtle enemies of motor insulation is moisture. Needless to say, motor insulation must be kept reasonably dry, although many applications make this practically impossible unless the motor is totally enclosed, or otherwise protected from the direct effects of moisture. If operated in a damp place, special moisture-resisting treatment should be given the windings. For this reason all above-deck motors are water-proof, as well as certain applications below deck, such as a pump motor located in the shaft alley.

**Dipping and baking.** The life of a winding depends upon keeping it in its original (or new) condition, as nearly as possible. In a new machine, the winding is snug in the slots; the insulation is fresh and flexible, being newly treated with varnish, and, therefore, resistant to the deteriorating effects of moisture and other foreign matter. This condition is best accomplished by periodic cleaning, followed by varnish and oven treatments. (See sections on Cleaning and Drying.)

One condition which frequently hastens winding failure is movement of the coils due to vibration during operation. After insulation dries out it loses its flexibility and the mechanical stresses caused by starting and plugging, as well as the natural stresses in operation under load, will precipitate short circuits in the coils and possibly failures from coil to ground, this usually at the point where the coil leaves the slot. The effect of periodic varnish and oven treatments properly carried out so as to fill all air spaces caused by drying and shrinkage of the insulation, thereby maintaining a solid winding, will also provide an effective seal against moisture.

## MAINTENANCE OF ROTOR WINDINGS

The rotors of wound rotor motors have many features in common with the stators; therefore, the same comments apply to the care of rotor windings as are given for the care of stator windings. However, the rotor introduces some additional problems due to the fact that it is a piece of rotating machinery.

Most wound rotors have a 3-phase winding, and are, therefore, susceptible to the same trouble of single phase operation. The first symptom of an open rotor circuit is lack of torque, slowing down in speed, accompanied by a growling noise, or perhaps failure to start the load. The first place to look for an open secondary circuit is in the resistance bank or the control circuit external to the rotor. Short-circuiting the rotor circuit at the slip rings and then operating the motor will usually determine whether the trouble is in the control circuit or in the rotor itself. It may be in one of the stud connections to the slip rings.

If the rotor is wave wound, the windings being made up of copper strap coils with clips connecting the top and bottom half of the coil, it will be well to inspect these end connections for possible signs of heating, which would be an indication of a partial open circuit. Faulty or improperly made end connections are a common source of open circuits in rotor windings.

A ground in a rotor circuit will not affect the performance of the motor unless another ground should also develop, which might cause the equivalent of a short circuit, in which case it would have the effect of unbalancing the rotor electrically. In addition to reduced torque, another symptom of this condition might be excessive vibration of the motor; also sparking and uneven wear of the collector rings.

Another—and a reasonably successful manner of checking for short circuits in the rotor windings—is to raise the brushes off the slip rings and energize the stator. If the rotor winding is free from short circuits it should have little or no tendency to rotate, even when disconnected from the load. If it does evidence considerable torque, or tendency to come up to speed, the rotor should be removed and the winding opened and examined for fault. In making this test note that some rotors having a wide tooth design may show a tendency to rotate even though the windings are in good condition.

Another check which can be made with the rotor in place and the stator energized, also with the brushes raised, is to check the voltage across the rings to see if they are balanced. Judgment will have to be used in making this check to make sure that any inequality in voltage measurements is not due to the relative positions of the rotor and stator phases. In other words, the rotor should be moved to several positions in taking these voltage measurements.

**Squirrel cage rotors.** Squirrel cage rotors are more rugged and in general require less maintenance than wound rotors, but may also give trouble due to open circuits or high resistance points between the end rings and the rotor bars. The symptoms of such conditions are in general the same as with wound rotor motors, that is, slowing down under load and reduced starting torque. Such conditions can usually be detected by looking for evidence of heating at the end ring connections, particularly noticeable when shutting down after operating under load.

Any fractures in the rotor bars will usually be found either at the point of connection to the end ring or at the point where the bar leaves the laminations. Discolored rotor bars are also evidence of excessive heating.

Brazing broken bars or replacing bars should be done only by a competent person. Considerable technique is required for this kind of work, and it is recommended that the manufacturer's service department be consulted before attempting such repairs unless an experienced operator is available, or except in an extreme emergency at sea.

## THE AIR GAP

It has been stated that a small air gap is characteristic of the induction motor. The size of the air gap has an important bearing on the power factor of the motor and in doing anything to affect this, such as grinding the rotor laminations or filing stator teeth, the fact that the magnetizing current will be increased, with resultant lower power factor, should be kept in mind.

Good maintenance procedure calls for periodically checking the air gap with a feeler gage to insure against a low bearing permitting the rotor to rub the laminations. These measurements should be made on the pulley or gear-end of the motor.

On large machines it is desirable to make a record of these checks, four measurements being taken approximately 90° apart, one of these points being the load side, i.e., the point on the rotor periphery which corresponds with the load side of the bearing.

A comparison of the measurements taken with those previously recorded will permit the early detection of a bearing going down.

A very slight rub will generate heat sufficient to destroy the coil insulation.

## OVERLOADING AND SINGLE PHASE OPERATION

All too frequently a motor of adequate capacity properly applied to the original application is later found to be overloaded or otherwise unsuited for its job, due for example to more severe duty imposed on the machine, or changed machine operations.

Connecting instruments in the motor circuit will quickly disclose the reason for any tendency of the motor to overheat, failure to start the load, or other abnormal symptoms. It is also frequently desirable to connect recording instruments in the motor circuit for other purposes, such as analyzing the output of the machine, as a check on the operator, or to gage processing operations. With enclosed wiring this is usually rather difficult. However there are on the machine standard sockets for electrical instruments, providing a ready means of plugging into a circuit either recording or indicating instruments without necessitating the usual shutdown. The accompanying illustrations (Fig. 84) show how the installation of the standard socket in a motor circuit provides a ready means of obtaining either continuous or periodic checks, by plugging in any one of a complete line of plug type meters or instruments, as well as an analyzer. See the section on Inspection.

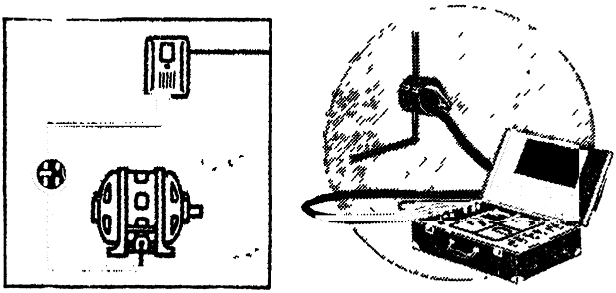


FIG 84 Socket instruments Left: motor circuit with meter socket installed. Right: handy test jack, which permits conventional analyzers or portable instruments to be plugged easily and quickly in the circuit.

Control circuits for many of the older induction motor installations were not provided with relay protection, and single phase operation of polyphase induction motors on such circuits has frequently been responsible for motor burnouts. Usually this has resulted from the blowing of one of the fuses, while the motor is up to speed and under load. Under such conditions the portion of winding remaining in the circuit will endeavor to carry the load until it fails due to overheating

FIG. 85. Section through thermostatic relay, providing protection against sustained overloads. At right is shown reset button.

One possibility of overloading is to drive a "backward curved" bladed ventilator blower backward, which would similate a "forward curved" bladed blower.

The effect of increasing the load on the motor beyond its rated capacity is simply to increase the operating temperature, which shortens the life of the insulation. Momentary overloads usually do not damage, consequently the tendency to the thermal type of overload protection in present-day control. Obviously the ideal place to measure the thermal effect of overload is on the motor itself. This is readily obtained through the use of the device in Fig. 85, a small thermostatic relay usually put in direct contact with the windings. This provides an effective protection against failure due to sustained overload by breaking 2 circuits in series.

Without doubt the polyphase induction motor is the simplest and most fool-proof piece of rotating electrical apparatus. The largest single cause of winding failures is probably due to the *rotor rubbing the stator iron,* usually because of worn bearing or complete failure of the bearing. The subject of bearings and lubrication is a large one in itself, and since it applies to all types of rotating electrical apparatus manufacturer's instructions should be carefully followed.

## STARTERS FOR AC SQUIRREL CAGE INDUCTION MOTORS

Starting equipment for squirrel cage AC motors may be divided into the following general types.

**Manual starters.** Manual starters up to about 1 HP (modern practice) are used to connect small motors directly to the line. The oil immersed drum type is used extensively wherever the air may become charged with corrosive gases or highly inflammable particles of dust or lint. The drum type is frequently made for reversing service, and also for smaller multi-speed squirrel cage motors.

**Magnetic linestarters.** Magnetic linestarters are suitable over a wide horsepower-voltage range. Linestarters are used where the design of the motor and the capacity of the circuit permit, and where the advantages of simplicity and remote control are desired. They may also be used as primary switches for wound rotor motors in combination with suitable secondary controllers.

**Reduced voltage starters.** Reduced voltage starters, both manual and automatic, range from about 5 to 200 HP. Starters of auto-transformer type find extensive application where the size or design of the motor or restrictions of the supply circuit require starting on reduced voltage. The auto-transformer type starter provides greater starting torque per amp.

starting current drawn from the line than any other type of reduced voltage motor starter.

**General rules.** On all of these types, the following general considerations must always be observed.

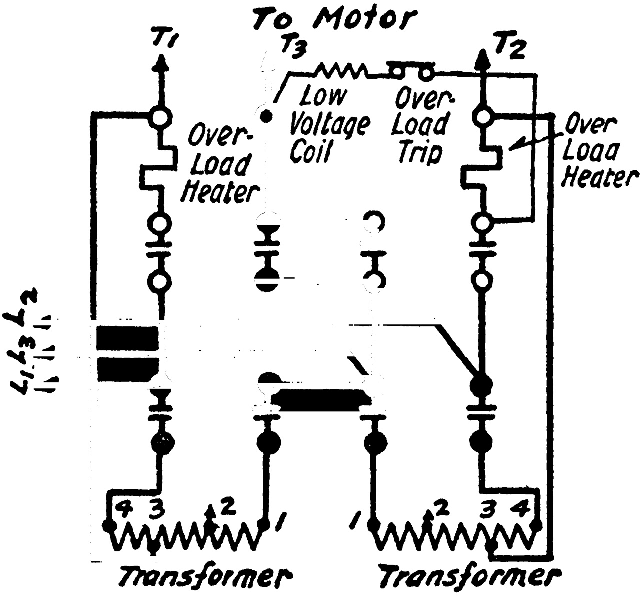


FIG. 86. Typical auto-starter, 3-phase wiring diagram. While 3-phase auto-starters are designed to start 3-phase motors and 2-phase auto-starters to start 2-phase motors, a 2-phase auto-starter may be used to start a 3-phase motor. To do this, connect L3 to L4 and T3 to T4. Then connect the line to L1–L3–L2 and the motor to T1–T3–T2.

1) Before removing cover to inspect or adjust starter make sure that disconnecting switch is open and control circuit dead.

2) Remember that all parts must be kept dry and clean. This is of fundamental importance.

3) Inspection should be made at regular intervals for best results. In general, monthly inspections will be sufficient, though in particularly severe service it may be desirable to inspect oftener.

**Maintenance of manual starters.** On the types employing a toggle switch with a quick make and quick break, there is practically no mainten-

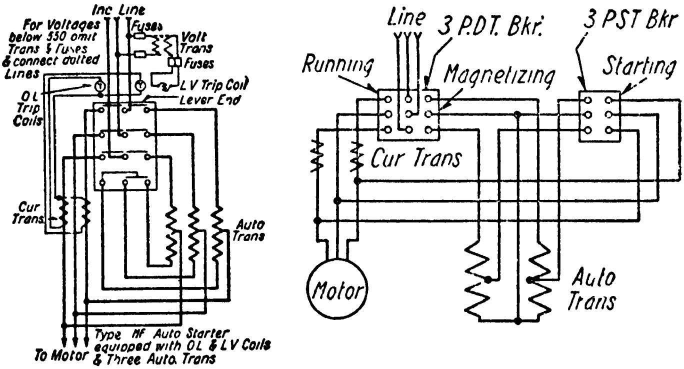


FIG. 87A. Left side shows diagram of connections for reduced voltage motor starting oil circuit breakers. Right side shows diagram of connections for 3-phase reduced voltage motor starting, using 2 oil circuit breakers and 2 autotransformers.

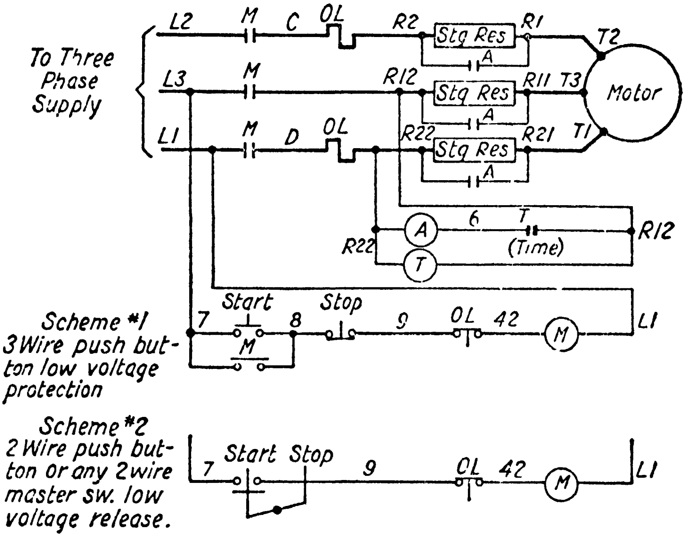

To Three Phase Supply
L2
L3
L1
M
C
OL
D
R2
R1
R12
R11
R22
R21
Stg Res
A
T2
T3
T1
Motor
6
T
(Time)
R12
R22
A
T
Scheme #1 3 Wire push button low voltage protection
Start
Stop
7
8
9
OL
42
M
L1
Scheme #2 2 Wire push button or any 2 wire master sw. low voltage release.
7
Start Stop
9
OL
42
M
L1

FIG. 87B. Typical diagram for a resistance starter. Resistance inserted in the primary circuit is cut out gradually by the starter as the motor comes up to speed. They are usually designed to short circuit the resistor in from 1 to 10 seconds, and for starting not more than once every 80 seconds.

ance except to check tightness of connections and be sure that heaters for overload relay are tight.

On the oil immersed drum type, it is well to:

1) Check all connections.

2) Observe wear on removable contact tips and replace when ⅔ worn away.

3) Replace oil when it becomes dirty or badly carbonized.

4) See that all parts are clean and move freely.

**Maintenance of magnetic linestarters.** 1) Do not lubricate contact tips or bearings.

2) Magnet sealing surfaces should occasionally be wiped with an oil-moistened cloth to prevent noise and rust.

3) Check tightness of all connections, and particularly connections to overload heaters, since a loose connection here will cause local heating that will affect the calibration of the relay.

4) Make sure that shunts are not broken or touching other parts.

5) Contacts should be adjusted so that they will all make at the same time.

6) In general, the contacts will not need attention during normal life. If they become excessively rough or burned in service, they should be dressed with sandpaper or a fine file. Do not use emery cloth. Contact tips should be replaced when approximately ⅔ of their thickness is worn away. These are removable, and only a screw driver is needed for the change.

7) Any excess deposits should be removed from the inside surfaces of the arc boxes adjacent to the contacts, and any broken arc boxes should be replaced.

8) See that all moving parts work freely.

9) Disconnect motor and manually test the start button, the stop button, the overload relay and reset.

10) Most linestarters are provided with overload relays whose action depends on the movement of a bi-metallic strip under heat. On very small motors the bi-metallic strip actually carries the motor current, but, on larger ones a separate heater carrying the motor current is placed close to the strip. On still larger motors a current transformer reduces the motor current to a value that can be handled by the heater.

**Thermal overload relays.** These thermal relays have the inverse time limit feature which means the greater the overload, the shorter the time of tripping. They provide excellent protection against overloads and momentary surges but do not protect against short circuit currents. For protection against the latter, fuses not exceeding four times the motor full load current, time limit circuit breakers set at not more than four times the motor full load current, or instantaneous trip circuit breakers should be installed ahead of the linestarter. Where fuses are used it is good practice to use a disconnecting switch as well.

Heaters for thermal relays are made with different current ratings, so that within its limits any starter can be used with different size motors and still afford proper protection by selecting the size of heater that corresponds to the full load current of the motor being used. Tables showing the ampere rating of heaters can be obtained from the manufacturer. In general, the amp. rating of the heater should be approximately 120% of the motor full load current.

A further adjustment is possible by means of a calibration lever on some types of relays. When set at 100% the current stamped on the heater will just trip the starter after several minutes. For tripping at a smaller current move the lever toward 90; at a larger current toward 120.

**Maintenance of reduced voltage starters.** The maintenance requirements listed under linestarters apply also to reduced voltage starters commonly known as auto starters. In addition the following points should also be checked.

1) The moving part of the low voltage release mechanism should be carefully examined to see that it works freely.

2) Many of these starters use an overload relay of the magnetic type having an oil-dash pot to prevent tripping on momentary overloads. Care must be taken to see that the piston is not binding in the dash pot and that the dash pot is filled to cover the piston with the proper grade of dash pot oil.

3) The setting of the overload relay should be checked and should be at least 125% full load motor current. Read the setting where the calibration line on the dash pot coincides with the bottom of projection on the upper casting.

4) Above 35 HP at 25 cycles and above 50 HP at 60 cycles, and above 550 v. it is customary to use insulating oil in the pan so that contacts will make and break under oil. The pan should be filled with oil to the oil level mark. If the oil becomes badly discolored or carbonized from service, it should be replaced with new oil after carefully cleaning the pan.

5) In automatic starters of this type a definite time relay is used to control the time on the starting tap. The timing of this relay should be checked, and, if a type using an oil dash pot, is employed, care must be taken to see that it is filled with oil.

6) The starting transformers are provided with taps by which the starting voltage can be varied. The proper taps to use are those that will bring

the motor up to speed in 20 sec. or less on motors up to 100 HP. On 200-HP motors the starting period may be 30 sec. Times longer than these may seriously overheat the transformer.

**Maintenance of resistance type starters.** Since practically all starters of the resistance type employ drum type controllers in the smaller sizes and contactors in the larger, the maintenance requirements are covered by the preceding sections. They are called resistance type, because resistance inserted in the primary circuit is cut out gradually by the starter as the motor comes up to speed. They are usually designed to short circuit the resistor in from one to ten seconds and for starting not more than once every 80 sec. See also Chapter V, Motor Starting and Control Equipment.

**Renewal parts.** Good maintenance demands a stock of renewal parts on hand so that they are available when needed. This is especially true where the service is severe. It is well to have stationary and movable contacts, magnet coils and shunts. On auto starters a spare auto transformer sometimes comes in mighty handy. The comparatively small cost of these parts is so much less than the delay and loss of production ordinarily caused by a shutdown that they represent very desirable insurance.

## STARTING AND SPEED REGULATING RHEOSTATS AND CONTROLLERS FOR AC WOUND ROTOR MOTORS

**General.** Rheostats of face plate type with self-contained resistors are used in conjunction with manual or magnetic primary control for starting and for speed regulation by secondary control of AC wound rotor motors ranging from ¼ to 25 HP. For reversing service and heavier duty applications drum or drum contactor controllers are used with separately mounted resistors, the standard drum controller being used for ratings from ½ to 100 HP and for the heaviest duty applications the drum contactor type is used for ratings from 2 to 300 HP.

**Maintenance requirements.** Special attention should be given to the maintenance of the secondary control of wound rotor motors, particularly those used in speed regulating service, since in a large percentage of applications it is possible for faults to develop through normal wear without causing either immediate shutdown or failure to start. A similar fault in the primary circuit would force immediate correction of the trouble.

Since the motor will continue to start and operate even though an actual open circuit or serious unbalance of resistance may exist in the secondary circuit at certain points on the controller, it is not always understood or appreciated that this condition may result in (1) roasting out of the rotor windings, (2) burning of brushes and collector rings, (3) overheating of resistors.

Also, undue stress on the equipment may be produced when smooth steps of acceleration provided by control are lost by poor or no contact at certain points on controller. Such conditions may develop without the operator either noting or reporting any difficulty until serious breakdown occurs, when it will be recalled that they "did have to notch the controller up a step" or that "it has jumped a bit on that point."

A definite and regular inspection schedule is essential, not only for these reasons, but also because this class of apparatus is of such rugged design and construction that it requires a minimum of attention and may therefore, be neglected.

**General maintenance.** To insure against service interruptions and keep all types of secondary controllers in good operating condition requires only regular inspection and cleaning and the maintaining of contacts. Some arcing and burning of contact making parts is unavoidable and these should be kept smooth to insure positive low resistance contact at all times. Sandpapering or occasional dressing with a file may be necessary. The contacts should be lightly lubricated with vaseline after dressing and cleaning.

Resistors can be readily checked for continuity by testing across rheostat contacts or controller fingers or preferably by raising brushes at the motor collector rings and connecting test lamp, ohmmeter or other available testing equipment across brushholders or outgoing leads and moving the secondary controller through its full sequence step by step. If repeated across each phase this will verify both continuity of resistors and tap connections as well as indicating any open contacts in controller. However, since the values of secondary resistance are relatively low, actual measurements of resistance values on each step are not possible with equipment available in many plants and in these cases more careful visual inspection must be made to locate and correct any loose connections or low pressure contacts. Tap connections on grid type resistors, if found movable by hand or showing evidence of heating, should be removed, cleaned, replaced and pressure of contact increased by taking up on the pressure nuts at the ends of the grid assembly. On ribbon wound resistors the clamp type connections should be tightened if not solid.

**New installations.** On new installations, at least two inspections should be made at short intervals after placing in service to insure that all contacts remain tight after heating and cooling of resistors in service. Since a large amount of heat energy is liberated from resistors, equipment must be located to allow adequate air space and ventilation.

**Face plate types.** Rheostats for starting duty only are provided with a return spring and latch in the full speed position so the arm cannot be left on intermediate positions. When inspected, these types should be checked to see that the arm returns freely to the start position except when latched, since if operated at intermediate positions, resistors will be overloaded.

Rheostats for speed regulating duty are designed for continuous operation on any step and the return spring and latch are omitted.

Most of these types are designed with reversible stationary contacts which may be turned over when they become worn or burned. When turning over, all surfaces should be dressed to remove oxide and insure positive contact. Surface level of adjacent contacts should be checked to insure that moving contact will bridge with firm pressure on each stationary contact.

## CONTACTORS

**Inspection.** Obviously no general rule can be given for frequency of inspection. Some contactors have to be inspected every day. A regular schedule should be arranged so that all contactors in actual service are gone over at least once a month. Add to this as equally important, an adequate stock of renewal parts.

Many old style contactors with horizontal pull on the magnets give trouble under extreme conditions, such as vibration from accidental closing. Modern contactors having vertical lift solenoid mechanisms cut maintenance cost and increase safety.

To quote from the section on Maintenance, "The first requirement in the satisfactory maintenance of electrical apparatus is competent inspection." This is probably as good an introduction as can be found for any subject dealing with maintenance. Competent inspection means knowing the function and the physical relation of every part of the piece of apparatus with reference to each other and the whole, therefore, it becomes necessary for intelligent maintenance, to follow carefully the manufacturers' instruction leaflets or instruction books applying to any particular piece of apparatus.

Contactors are applied in control as well as power circuits, singly and in groups, with load currents on the main contacts ranging from fractions of an ampere to thousands of amperes, but whatever the application, the maintenance in general is the same with the exception of frequency of attention.

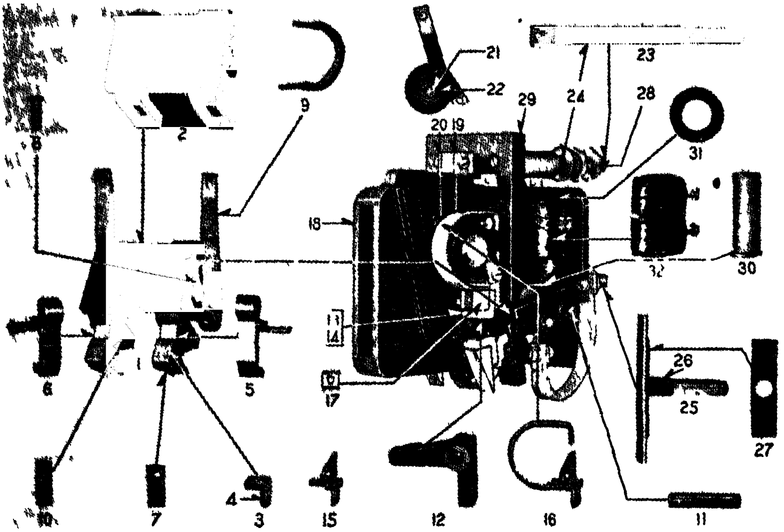


Fig 88 Westinghouse Type SM contactor, magnet closed

## LIST OF PARTS

| | |
|---|---|
| 1 | Armature Complete with Arc Horn |
| 1 | Armature Complete without Arc Horn |
| 2 | Armature Lever and Plate |
| 3 | Moving Contact |
| 4 | Moving Contact Screw |
| 5–6 | Moving Contact Support |
| 7 | Arc Horn for Moving Contact |
| 8 | Moving Contact Hinge Pin |
| 9 | Shunt Complete |
| 10 | Spring |
| 11 | Armature Shaft |
| 12 | Bearing Bracket |
| 13 | Stationary Contact |
| 14 | Stationary Contact Screw |
| 15 | Stationary Contact Support |
| 16 19 | Stationary Contact Support with RH Blowout Coil and Upper Arc Horn |
| 16 20 | Stationary Contact Support with LH Blowout Coil and Upper Arc Horn |
| 17 | Arc Horn for Stationary Contact |
| 18 | Arc Shield |
| 21 | Insulation Tube for Blowout Coil |
| 22 | Washer for Blowout Coil |
| 23 | Stud and Insulation—Upper |
| 24 | Insulation Tube |
| 25 | Stud and Insulation—Lower |
| 26 | Insulation Tube |
| 27 | Insulation Strip |
| 28 | Nut for Stud |
| 29 | Base |
| 30 | Stationary Core |
| 31 | Spring Washer for Operating Coil |
| 32 | Operating Coil |

## DIRECT-CURRENT CONTACTORS

These contactors are equipped with or without magnetic blow out coils, depending on the circuit application In general, all wearing parts are made of steel or bronze and all metallic parts are treated in some manner in order to prevent corrosion Arc shields are made of moulded heat resisting compounds and are so arranged that they can be removed or rotated out of the way in order to inspect the main contacts. Some contactors are equipped (here again the application is the determining factor) with arc splitters for quickly cooling, lengthening and rupturing the arc. The main contacts are in general made of copper (some special applications use silver or other materials as dictated by the application) and close with a rolling movement combined with a wiping action which insures good contact and confines the arcing with resultant burning to the tips of the contacts. Conventional contactors are spring loaded to insure positive contact pressure and to accelerate the opening of the contacts.

**Maintenance.** The use of a lubricant on the contacts or bearings of a contactor is to be avoided. Oil quickly collects dust and unless parts are frequently cleaned, will interfere with the operation of the contactor. Oily surfaces that collect dust may also result in an arc between live parts of the contactor.

Flexible braided copper shunts are designed to give complete freedom to the moving armature with sufficient current carrying capacity. Burned or badly corroded shunts should be replaced promptly.

The contacts normally wear to give the best contact surface without any attention. The roughened appearance of the contacts is no indication that good contact is not being obtained, but of course any little globules of copper that prevent the contacts from seating should be dressed off. When the contact surfaces are burned to such an extent that the current carrying surfaces are materially affected, they should be replaced.

**Check contact pressure to avoid excessive heating.** Contact pressures can be checked to insure they are as required by the manufacturer, by the use of a spring balance as follows. Insert a piece of tissue paper between the mechanically tightly closed contacts. Fasten one end of the spring balance to the mounting screw of the moving contact tip and read in pounds the pull required to loosen the paper between the contact tips. In case the contact pressure is below the minimum value required, install a new spring. Low spring pressure should be guarded against to avoid excessive heating of the contacts. Excessive heating increases the resistance which may cause sufficient arcing to weld the contacts together.

There is probably no general rule applicable to contact pressure of a contactor. The manufacturer's recommendations should be followed. Table 2 shows the range of contact pressure which should be maintained on various AC and DC contactors widely used. This information will give a general idea for other contactors of similar types.

The contact gap should be maintained in accordance with the manufacturer's instruction. The gap is measured at the heel of the contact with the contactor in the full open position. Too great a gap may prevent the contactor from picking up or closing on the minimum voltage for which the operating coil is designed. It is important to check this gap on contactors which have been in service long enough to require frequent rebuilding.

Arc shields should always be down so that the arc is broken within the field of the blow out coil, otherwise the shield will not give satisfactory results.

Arc shields should be renewed before the moulded material is burned away sufficiently to expose the metal parts to the arc.

The sealing surfaces of the magnet core and armature should be kept clean to insure proper contact. The moving armature on its hinge pin is so arranged in most designs that it is self-aligning. Excessive wear or damage to the mechanism may make it necessary to replace worn or damaged parts to obtain proper alignment. Often removal of high spots on the contact surfaces of the moving and stationary armatures by filing, will remedy improper alignment.

Operating coils are designed to operate the contactor successfully with a voltage that varies from 80% to 110% of the normal rated voltage of the coil. All connections to the coil should be kept clean and tight.

## TABLE 2

RANGE OF CONTACT PRESSURE TO BE MAINTAINED ON TYPICAL WESTINGHOUSE CONTACTORS

| Type of Contactor | No. Poles | CP* | Type of Contactor | No Poles | CP* |
|---|---|---|---|---|---|
| 30-C | 1 | 3–4 | 35-F | 2 | 3–3½ |
| 40-C | 1 | 6–7½ | 45-F | 2 | 6–7½ |
| 50-C | 1 | 12–14 | 55-F | 2 | 12–14 |
| 62-C | 2 | 18–22 | 62-F | 2 | 18–22 |
| 72-C3 | 2 | 32–36 | | | |
| 82-C3 | 2 | 47–52 | 35-F | 3 | 3–3½ |
| | | | 45-F | 3 | 6–7½ |
| 101-SM | 1 | 6–8 | 55-F | 3 | 12–14 |
| 102-SM | 1 | 9–12 | | | |
| 104-SM | 1 | 20–25 | 37-F | 5 | 3–3½ |
| 108-SM | 1 | 20–25 | 47-F | 5 | 6–7½ |
| | | | 57-F | 5 | 12–14 |
| | | | 67-F | 5 | 24–26 |

Contact pressure at heel of contact tip measured in pounds.

Auxiliary contacts, if there be any, should be checked to insure that they have the correct travel, correct pressure, the contact surfaces are clean and that all connections to the auxiliary contacts are clean and tight.

Failure to close may be due to one of the following:

1) Operating coil may be open circuited.
2) Lead wires to operating coil may be loose or disconnected.
3) Excessive mechanical friction.
4) Power off or voltage below normal.

Failure to open may be due to:

1) Mechanical interference or friction.
2) Welded contacts.
3) Broken contact spring.

Adequate maintenance requires that sufficient renewal parts be carried in stock to replace broken or worn parts when required.

## ALTERNATING-CURRENT CONTACTORS

One of the principal and, without doubt, the most interesting differences between the conventional AC contactor with magnetic blow out coil and the modern AC contactor, is the De-ion arc quencher. De-ion arc quenching action confines, divides and extinguishes the arc almost instantaneously as the circuit is broken. The usual flash and scattering of flame outside the arc box is done away with.

How this is accomplished is shown by the sketches, Fig. 89. De-ion action not only stretches the arc, as by old method, but confines and quenches it. As the specially shaped contacts separate, a magnetic reaction occurs that forces the two stretching arcs to join across the stationary contacts. Here it rises immediately into the De-ion grids

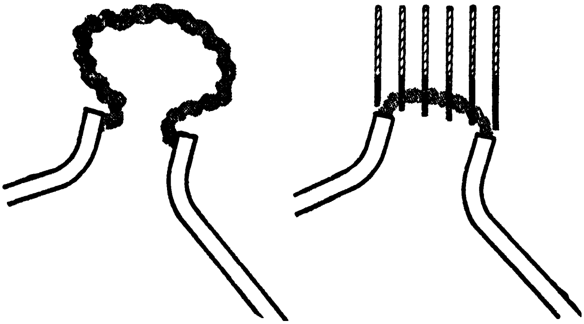


**Fig. 89.** Arc quenching, old method at left, and modern De-ion method.

where it is "sliced" into a series of arcs. At the next zero point on the current cycle, the air adjacent to each grid is de-ionized instantly, the voltage per grid is insufficient to re-establish the current flow, and the arc is "out."

Safety is thus assured and higher overload capacity made possible. Pitting and burning of contacts and arc box is greatly reduced and longer, trouble-free life provided than ever before considered possible.

The arc quencher is assembled over the contacts in much the same manner as the magnetic blow out coils and arc shields on the conventional contactor and is easily removed for inspection of the contacts.

Another difference is that shading coils are used in the face of the stationary core of AC contactors to reduce the magnetic hum.

**Why is a shading coil used?** In a single-phase, alternating-current magnet without some modifying feature, the pull is proportional at all times to the instantaneous value of the exciting current and reaches zero twice every cycle. The result is that the magnet starts to open every time the pull reaches zero. The mass of the moving part is usually large enough to prevent complete opening during this small interval of time, but there is enough movement to cause severe chattering and noise.

In a polyphase magnet the pull is continuous since the voltages impressed upon separate phases overlap each other.

To produce a relatively quiet single-phase magnet then, the problem is to obtain the equivalent of polyphase conditions. This is accomplished by the use of a shading coil or short-circuited winding placed around part of the pole face. The current induced in this shading coil produces a flux in that part of the magnetic circuit surrounded by the shading coil which is out of phase with the main flux. The combination of these two fluxes produces a pull which never reaches zero.

**Maintenance.** The information just given for DC contactors applies to AC contactors as well. However, due to the possible hum in the magnet it is imperative that the surfaces of the moving and stationary armatures be in the best possible alignment.

If the humming should become excessive, check the following: (1) The sealing surfaces of the magnet may be corroded, thus keeping the magnet from sealing perfectly. (2) The mechanical parts of the magnetic surface may be so distorted that the moving armature cannot find a square seat. Check this by closing the contactor electrically after placing a sheet of tissue paper between the surfaces. (3) The voltage may be low. (4) The shading coil may be broken. (5) Spring pressure may be high.

**Oil immersed contactors.** The tanks of oil immersed contactors should be kept filled to the proper level. Use only the proper oil.

In general, oil immersed contactors should have the same attention as oil circuit breakers of comparable voltage.

**DC magnetic brakes.** Winches, capstans and anchor windlasses when motor-driven, are equipped with automatic brakes. Fig. 90 shows a typical water proof magnetic brake. The solenoid at the left releases the brake shoes when the motor current is applied. The magnet travel which controls the brake shoe release must be kept in proper adjustment. As the brake shoes wear the magnet travel increases. This increase must be compensated for by shifting the adjusting nuts on the connecting rod. Experience only can tell you how much to move the nuts on a brake that has been in service for some time. Fig. 91 illustrates the construction of the solenoid magnet.

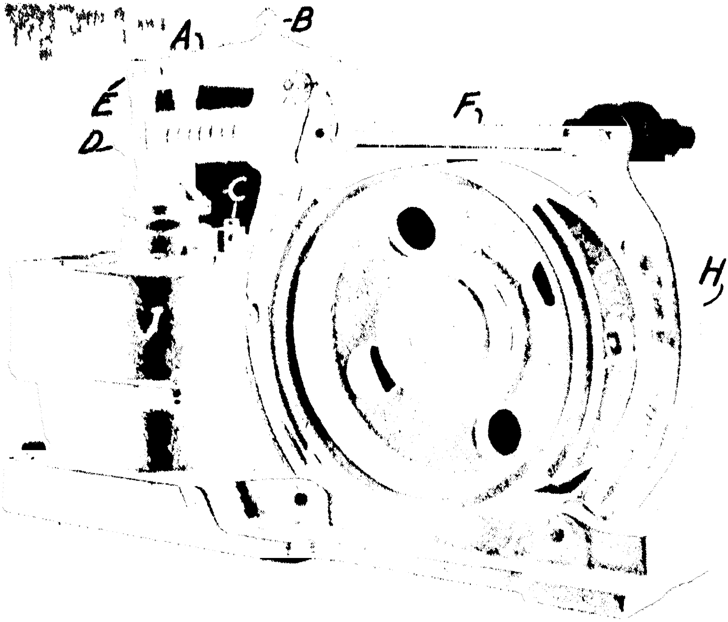


FIG. 90. Waterproof magnetic brake. *A*) Brake lever. *B*) Mechanical release mechanism. *C*) Adjustment for equalizing shoe clearance. *D*) Adjustment for regulating braking torque. *E*) Linkage. *F*) Connecting rod. *G*) Brake shoe. *H*) Front brake arm. *I*) Lower brake arm pin. *J*) Magnet. *K*) Brake wheel.

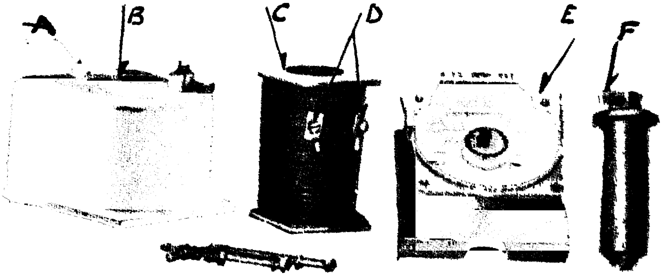


FIG. 91. Construction of solenoid magnet *A*) Upper half of magnet housing. *B*) Alloy spacers to prevent freezing. *C*) Operating coil *D*) Terminals. *E*) Machined surface between upper and lower housings. *F*) Plunger, with tapered end to give constant air gap

## BEARINGS AND LUBRICATION

*Under Direct Current Motor, pages 207 and 208, the subject of bearings was covered in a limited way. It is the purpose here to expand this material and cover the principal types of bearings in general use, because maintenance electricians are vitally interested.*

Bearings and lubrication are of the greatest importance regardless of the size of the apparatus. For example, an analysis of induction motor failures shows the bearings to be the principal offenders This follows because failure of a bearing allows the rotor to rub against the stator.

**Sleeve bearings.** In the electrical field, probably the most generally used bearing is the sleeve type. In recent years, the simpler sleeve type bearings have been largely superseded by the sealed sleeve type, which requires very little attention, since the oil does not become contaminated and oil leakage is negligible.

**Ball and roller bearings.** The real advantage of the ball and roller types of bearings over the sleeve type is in the starting friction which is practically the same as the running friction This unfavorable comparison does not apply under running conditions, when the oil film has been established.

**Kingsbury thrust bearings.** While other types of bearings are used to carry thrust, Kingsbury thrust bearings will be covered in this discussion.

## SLEEVE BEARINGS

Sleeve bearing design in general is based on the fluid theory of lubrication developed about fifty years ago, principally by Prof. Osborne Reynolds.

Reynolds showed that the oil because of its adhesion to the shaft, and because of its viscosity or resistance to flow, is by the rotation of the shaft, dragged along so as to form a wedge shaped film between the shaft and the bearing. This action sets up a pressure in the oil film which in turn supports the load on the bearing. This film completely separates the bearing surfaces so that there is no metal to metal contact. There is, therefore, no bearing wear when running.

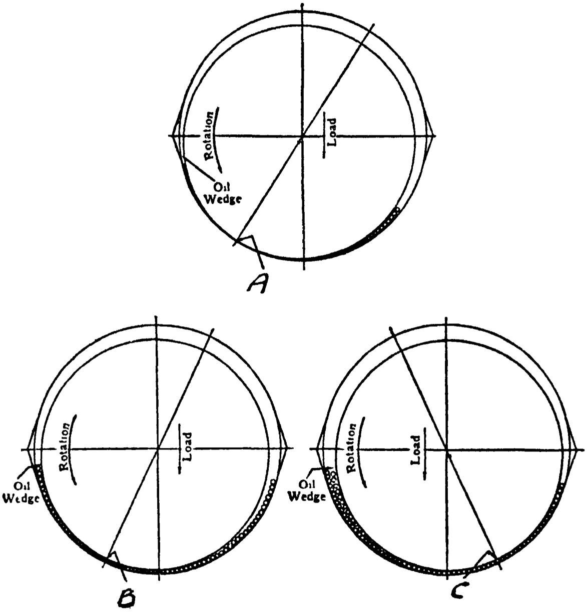


FIG. 92. Oil film and load directions in a sleeve bearing under different conditions. *A*) Point of highest pressure of shaft on bearings. *B*) Point of highest pressure on oil film at moment of breaking metal to metal contact of shaft with bearing surface. *C*) Point of nearest approach of shaft to bearing surface when oil film is fully established.

This wedge shaped film of oil was shown by Reynolds to be the absolutely essential feature of effective lubrication. Without it, no great load can be borne on the bearing, except with the accompaniment of high friction.

The formation of the wedge shaped film of oil causes a slight lift of the shaft The thickness of this film has been carefully measured The range is from a little under one thousandth to a little over 3/1000 in The mean thickness of the film, however, is usually not more than 002 or 003 in at normal speeds

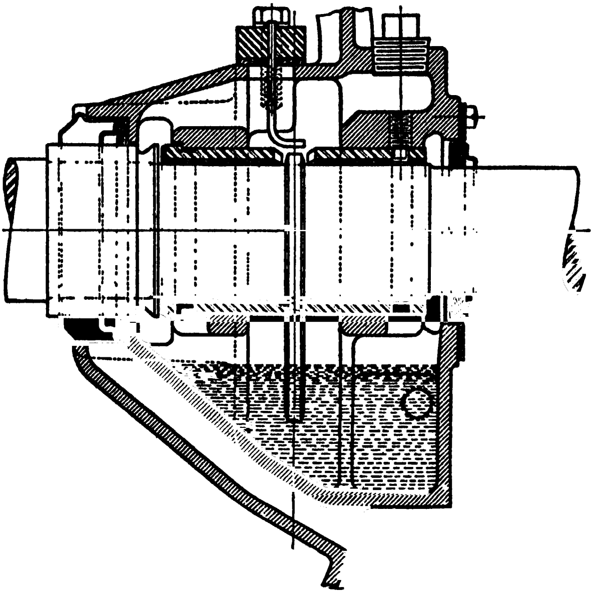


FIG 93 Cross section of a typical bearing sleeve assembly

Two outstanding considerations govern the design and maintenance of sleeve bearings. One is to insure at all times the existence of an oil film between journal and sleeve, and the other is to keep the destructive effects of metal-to-metal contact to a minimum when the oil film is lost as during starting, or by accident

**Coefficient of friction.** As an example, consider a conventional type motor.

If a hole were bored in the cast-iron bracket and the shaft allowed to slide around in it without a lubricant of any kind, the force necessary to apply at the periphery of the journal to cause rotation would be about 0 4 the weight of the rotor This is much too high for a practical bearing It would consume too much power and develop too much heat, even aside from the problem of bearing wear

Of course a good plain bearing carrying a heavy load in pounds per unit area when starting from rest after a period of idleness may require as much as half this amount of force at the moment of starting. This is the case, even if the bearing is provided with ring oiling in the customary manner, because the film of oil normally separating the journal from the bearing has been squeezed out to a large extent, but under favorable conditions of speed, load, and lubrication the frictional force to be overcome when running will often be as little as one one-hundredth of the dry friction.

This great reduction in friction to a coefficient (as it is called) of 0.004 is inherent in the oil film separating the moving and stationary parts of the bearing and clinging to each. Thus the rubbing or sliding phenomenon takes place in the oil film itself and the remaining friction in an ideal bearing becomes fluid friction almost entirely.

If the bearing were to run continuously under these conditions so that the journal does not come into contact with the bearing lining, and if dirt is prevented from getting between the bearing and the journal, piercing the oil film and scratching the metal surfaces, it should not be necessary to look after such a bearing oftener than every several years. Unfortunately these "ifs" are not always upheld.

All plain bearings, even with good film lubrication, do not have as low a coefficient of friction in operation as 0.004. In some exceptional cases it is possible to cut this figure in half, but on the average a somewhat higher coefficient is obtained. Friction in an oil film in a plain bearing is definitely dependent upon a number of important characteristics of the oil film:

1) Thickness of the film (governed largely by unit pressure and viscosity of the oil).

2) Viscosity or simply resistance to flow (determined by the nature of the oil and the temperature in the film).

3) Oiliness (principally dependent on the shape and arrangement of the oil molecules).

However, as long as the friction is confined to the oil film and there is reasonable facility for dissipating the heat, the bearing will be one that can be forgotten, even though, in shop parlance, it does "run hot."

While such a bearing is running normally it makes little difference of what materials the bearing or journal is made. A soft steel shaft in a cast-iron bearing is as good as any. However, a bearing is not always running; it is sometimes starting—in many cases, frequently starting—during which time the oil film is much impaired so that there may be metal-to-metal rubbing between shaft and journal. For such conditions contact of soft steel on cast iron, although better than soft steel to soft steel, is not the best combination. It becomes desirable to have dissimilar metals at the moving contact and also the materials should preferably differ widely in hardness.

Although the loss of oil film at starting or under slow motion with heavy pressure may give some concern and influence the choice of bearing materials, the most troublesome condition arises when the loss of oil film occurs at normal speeds. The oil film may be ruptured by any of several conditions: The shaft may be bowed or deflected by a heavy overhung load, such as occurs if the belt tension is excessive. The shaft may be bent during the handling or when it is pressed into a rotor or other part. There may be a misalignment of parts, so that the axis of the bearing is not exactly parallel to the axis of the shaft. The journal or bearing surface may not be exactly true.

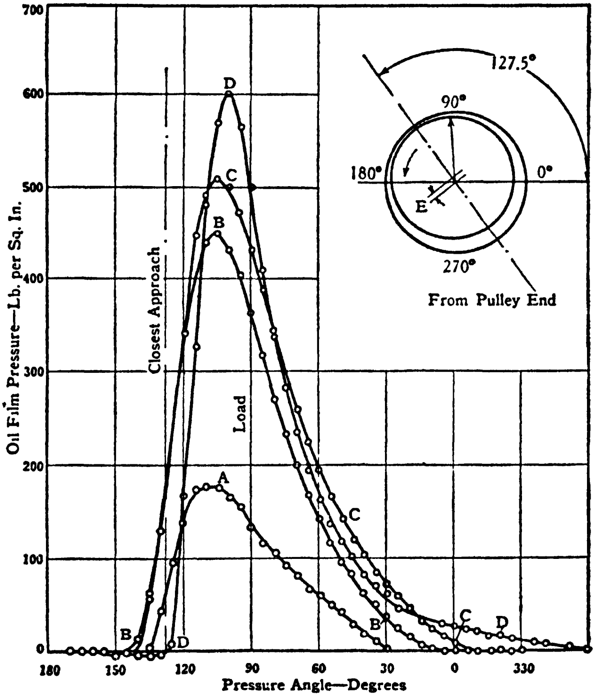


Fig. 94. Oil film pressures around a bearing of 2-1/2 in. diameter, and 5 in. long.

The bowed shaft resulting from too tight a belt or similar cause will probably not show up during manufacture or test of a motor. Bent shafts, misalignment, and high spots should show up while the motor is given its preliminary run. Frequently, such trouble will be indicated in the case of the smaller motors by the difficulty of turning the rotor by hand.

Slight metal-to-metal interference may not be particularly detrimental if the journal and especially the bearing material are wisely chosen. This possibility is indeed one of the controlling reasons for the choice of bearing materials usually made.

**Why use babbitt in bearings?** Isaac Babbitt, Taunton, Massachusetts, obtained a patent on Babbitt metal in 1839. This is probably one of the important basic inventions of modern times. Babbitt and high speed steel are U.S. contributions to modern metallurgy.

A good quality tin-base babbitt material will flow or "wipe" away at a small spot of interference as the shaft is rotated so that the interference becomes less and less until a thin oil film is established where metal-to-metal contact existed. If the interference is sufficient to cause trouble before wiping will clear it, heat developed will raise the temperature of the whole bearing housing. If the limits for temperature rise are properly chosen, the excessive rise noted will indicate to the observer that corrective measures should be taken. The bearing material that is used because it is self-clearing for slight interferences is easy to scrape so that more serious interferences can easily be removed.

Bronze bearings without a lining of softer material have been used for low-speed service. This material being much harder than babbitt will not accommodate itself as readily to the contour of the journal. High speed operation would, therefore, much more likely result in overheating and seizing; furthermore there is the possibility of hard particles in the bearing surface that tend to cut the shaft when metal-to-metal contact is established.

**Oil leakage.** It is a well known fact that oil rings carry a considerable amount of oil, far more than necessary for proper lubrication of the bearings. When running, most of this oil is carried on the outside diameter of the rings, due to centrifugal force. When passing through the oil ring slots and past the sight hole on bearing shell, a good deal of this oil is stripped off, causing splashing. It will be found that even at fairly moderate speeds, a spray issues from peep holes in bearing shell.

This spray may also reach the inner side of the covers in the housing cap, and spread to the outside surfaces by creepage. Air currents passing over these wet surfaces will pick up particles of oil and carry them into the machine. In order to overcome this difficulty, plugs should be fitted into the peep holes in the bearing shell. They may be attached by a short chain to the inner side of covers in housing cap, so that when lifting a cover for inspection, the plug is pulled up with it.

The oil rings also may cause a good deal of splashing. This is especially true at high speeds. This condition may be largely overcome by having baffles so arranged as to box in the oil rings, thus confining the oil turbulence.

The bearing split is a common source of trouble. The fundamental answer is to make sure that ample bearing surface is provided at the split, the two halves must be accurately machined and additional bolts should be used for proper hold-down. In some cases, an oil proof fibre gasket of suitable thickness, about 1/32 in. has been found to give good results.

It would probably be safe to say that most leakages are caused by air currents passing through the bearing housing, the result of blower action by the moving parts of the apparatus.

It is therefore essential to avoid such openings where the outside suction is high. Here is where the felt washer does good work.

It should be said here that the purpose of the felt washer is usually misunderstood. The belief exists that the felt is to prevent the oil from leaking out. This assumption is absolutely wrong and if conditions are so bad as to show that liquid oil escapes, then it is quite certain that the felt washer will not remedy the trouble for any length of time. Just as soon as the felt becomes oil soaked, the leakage will go on as before.

The purpose of a felt washer is, and should be at all times, to seal the housing against the air currents. Only as an air seal will the felt washer be of any real benefit. Even then, certain points will have to be observed:

1) Use the very highest grade of soft felt obtainable.

2) Use a felt washer not less than ¼ in. thick before compression.

3) Make a good mechanical job cutting the washer, so that inside diameter of the washer is true with edges at right angles to the surface of the felt. Make the inside diameter the same as the shaft, or a trifle under, but not over.

4) Make the sheet steel supporting washer with an inside bore larger than the shaft diameter by about twice the thickness of the felt. This permits the felt to expand next to the shaft and retain its resilience.

For all ordinary conditions, the felt washer has probably come nearest to solving the problem of oil leakage provided the suction is not very high. In cases, however, where the suction is high enough to create a vacuum at the housing face of ¼ in. of water or over, then other measures must be applied.

For these high vacuum conditions, it will probably be necessary to use some sort of an air by-pass such as is incorporated in most modern sleeve bearings. For old bearings, this often means considerable work.

Oil leakage is generally aggravated by high temperatures. See that bearings operate cool and use an oil which does not foam easily.

**Bearing currents.** The simplest and most practical way of testing for bearing currents is to see whether a small wire placed between shaft and pedestal will draw a visible spark. The presence of any spark at all is sufficient cause for assuming that bearing currents will flow unless prevented.

The pitting is caused by an arcing action across the oil film, currents under about 1¼ amps. per sq. in. harming the bearing only. Currents of greater density attack the shaft also.

It is difficult to measure the current, because the frequency is usually several times line frequency, and ordinary instruments are not suitable.

The most effective and usually the simplest method of protecting shafts and bearings against current is to place insulation under the pedestals or brackets. Usually an insulation thickness of ⅛ in. is sufficient, since the voltage (measured after insulation is applied) probably never exceeds 10 v.

From a maintenance standpoint, make sure that the bracket or pedestal insulation is not short circuited by metal thermostat or thermometer leads, or by piping.

Due to the reduced contact area of ball or roller bearings trouble is not unknown when these bearings are used.

**Oil film measurement.** An electromagnetic device for measuring oil films has been devised by the Westinghouse Research Department.

Two U-shaped electromagnets are mounted diametrically opposite each other, with a ring of laminations shrunk on the shaft, forming an armature. The electromagnets carry primary and secondary windings. The primaries are connected in series; the secondaries in series opposed. For a central

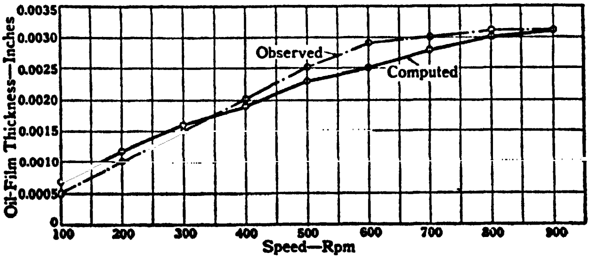


FIG. 95. Comparison of oil film pressures in relation to speed.

position of the shaft, the voltage in the secondary circuit is zero, and as the shaft moves the secondary voltage rises directly as the motion. This method was used on a bearing 9 in. in diameter and 18 in. long, subjected to a pressure of 150 lb. per sq. in.

A comparison of oil-film thicknesses as determined by calculation and as measured with the electromagnetic device described above. On all important installations the values of oil-film thickness are checked carefully. In finely bored small bronze bushings a film of about 0.001 in. is sufficient. For ordinary bearings with steel shaft and babbitted shell a thickness of oil film above 0.00075 in. should be maintained. These values, which have often been checked, appear to be well founded. (See Fig. 95.)

## BALL AND ROLLER BEARINGS

Sleeve bearings have done, and are still doing, a wonderful job in carrying the rotating burdens of the world and in reducing friction to a minute fraction of what would be possible without them. Indeed it is probably true that the best performance of sleeve bearings has not been exceeded by any other type. There are, however, two outstanding problems in connection with the use of sleeve bearings that have troubled engineers, and that have led to the development and increasing use of what are called, for want of a better name, anti-friction bearings, that is, ball and roller bearings.

The first of these problems is a fundamental one that concerns the separation of the rotating part of the bearing from the stationary part. In a sleeve bearing the separating medium is usually an oil film, as has been explained, and at rest there is no film.

Accordingly, engineers have developed the ball and roller bearings in which oil is displaced as the separating medium by a series of balls or rollers that remain between the stationary and rotating parts of the bearing whether in operation or at rest.

The second problem, although not exactly fundamental, has nevertheless been extremely troublesome. This concerns the fact that oil, which is distinctly the superior lubricant for sleeve bearings, necessitates special sealing arrangements to keep it within the bearing housing. The ball or roller bearing, grease lubricated, has therefore presented itself as a solution to this second major problem.

These advantages and others of a more minor nature have led to a broad and increasing use of this type of bearing. However, in spite of the fact that a very large majority of the millions of these bearings annually placed in service gives entirely satisfactory service, they furnish an engineer with a variety of problems, some of them serious. In other words, the solution of the problems of the sleeve bearing by substitution of a ball bearing has introduced problems of its own and the solution of these problems has given rise to still other problems so that the matter is not as simple as it first seems.

The ring of balls intended to replace the oil film of a sleeve bearing separates the rotating inner race of the bearing from the stationary outer race. Considering a horizontal shaft, the two or three balls directly below the shaft at any instant carry practically all the load. They do not slide but roll between the two races which they contact. The relation between the diameters of the inner and outer races at the place where the balls roll and the rotational speed of the inner race definitely determine the forward speed of these balls around the circle. They can move no slower and no faster than this speed without slipping. The other balls are not ordinarily under load.

Although they rotate on their axes, partially from the momentum gained while in the loaded position and partially from light contact with one or other of the races, they are not compelled to rotate at any particular speed and undoubtedly slow down in their rotational speed after they leave the loaded zone, thus giving a partial sliding contact with the inner and outer raceways. The tendency therefore is for these unloaded balls to lag and acquire a non-uniform spacing. If this were permitted, the balls would bind against one another as they passed into the loaded zone, resulting in improper operation.

The common solution for this problem is the introduction of a cage, separator, or retainer as it is variously called. Each ball has its own pocket in this separator. The loaded balls drive it around at a definite speed governed by their rolling contact with the raceways and it, in turn, drives the laggards. The balls in the separator pockets make sliding contact with the engaging surfaces The pushing around of balls and by balls indicates a load to be carried on these bearing surfaces so that the elements of a plain bearing are re-introduced. Lubricant thus becomes a necessity.

**Misalignment.** Under certain conditions this problem becomes worse. If misalignment is present, balls at different points around the circle may be loaded, artificially perhaps, but none the less forced to roll. The contact of these balls with the raceways will not be at a uniform diameter. The driven balls will therefore tend to rotate at different speeds. The actual speed will have to be reducd to uniformity against the pressure of the various driven balls. The load on the retainer is increased and a still greater need for lubrication arises. Thus we have a grease problem.

**Lubrication.** Many greases deteriorate in time and in service by either oxidation or separation or both.

In the case of separation, the oil comes out of the mixture and escapes, leaving a hard, flaky residue without any lubricating value and of an abrasive nature.

In the case of oxidation, the grease progressively becomes tacky and, if normally a yellow grease, discolored. Finally it becomes definitely sticky and gummy, like varnish. In this condition it cements the retainer to both inner and outer races and as the ball assembly runs at neither the speed of the outer race nor the speed of the inner race, the balls must drive the retainer with enough force to tear this sticky film. Meanwhile the interior of the bearing is sealed by this sticky film from any fresh supply of lubricant. The interior becomes dry and the sliding friction of the balls on the retainer surfaces under the various artificial loads described is not mollified by the anti-friction oil film. Dry metal-to-metal contact results in high temperatures and power losses and what is perhaps worse, abrasion of the metal of the contacting surfaces. The fine particles removed by abrasion are rolled under the balls and forced into the surfaces of the balls and raceways, causing roughness and noise. In the extreme case, the thin section of the retainer wears through and pieces of it get under the balls, causing complete destruction.

This problem has been recognized and several remedies suggested. Sometimes cast-bronze retainers have been used as a partial corrective measure, but, being bulky and heavy, they tend to interfere with the free passage of grease into the bearing and to hang heavily upon the balls or races.

Non-metallic retainers, such as those made of micarta, have been used instead of pressed steel or brass, cast bronze, or other metals. In small grinder spindles running at many thousands of revolutions per minute the life of the bearings has been increased from a few hours or days to several weeks or months by this substitution. They are light and flexible and are less sensitive to scanty lubrication. At such speeds as these, however, grease is not used; oil, in the form of mist, is the lubricant.

Retainer lubrication, although important, is not the only lubrication problem in ball and roller bearings. Roller bearings particularly have surfaces where sliding rather than rolling friction occurs and although the surfaces of the rolls which contact the races in this way and the corresponding surfaces of the races are extremely hard, a measure of lubrication must be provided if substantial loading is to be carried successfully.

Even balls, and everybody has heard that "nothing rolls like a ball," have a certain amount of sliding friction when under load. Under load the theoretical point of contact of the ball with the raceway spreads into an elliptical area. Because this area of contact is spread over curved surfaces, all points in the area of contact do not occur on circles of equal diameter.

A ball can run at only one speed and this will correspond to the diameter of the circle where the heaviest pressure occurs. Points at the ends of the elliptical area must slip. This slippage is very slight in the case of radial bearings and especially at light loads and is more pronounced in the case of angular contact bearings and specially at heavy loads.

**Corrosion.** Because of the small areas of contact between balls (or rollers) and raceways the unit pressure at these contacts is extremely high and necessitates the use of hard materials. These materials unfortunately are highly subject to corrosion, so much so that after the flood in 1936, ball and roller bearings in their cartons that had been submerged could scarcely be salvaged without regrinding if not washed and flushed in oil within a couple of days after the water subsided.

The highly polished surfaces of balls and raceways tarnish in air. Even such slight imperfections of surface interfere with satisfactory operation. This situation affords the lubricant another opportunity for usefulness—to cover the bearing surfaces at all times. Where oil-lubricated ball bearing motors stand idle for long periods, so that the oil may drain from the bearing surfaces, trouble may be experienced from corrosion.

Not less harmful are corrosive ingredients that may be contained in the lubricant or which may be developed in the lubricant over a period of time. This serves to emphasize the great importance of choosing the correct lubricant for the application.

**Dust and dirt.** Motors often operate in very dirty places. Even in applications considered average as far as abrasive atmospheric dust is concerned, the abrasive particles may penetrate the housing seals and reach the important bearing surfaces. Cast iron dust not removed from the housing parts after machining operations may greatly increase its abrasive character by combining with oxygen to form iron oxide. This is the material used to polish glass; it cuts the steel surfaces rapidly.

Carelessness in keeping grease or oil containers closed permits abrasive dust to enter the bearing through the lubricant. Even fine brass cuttings, worn from housing seals by rubbing contact with the shaft, mixed with the lubricant makes an effective lapping compound. The fact that the brass is softer than the hard steel surfaces of the bearing does not prevent the abrasive action.

Sometimes these abrasive particles lodge in the surface of the relatively soft retainers, creating a most effective lapping device. Retainers that present edges rather than surfaces of their materials to the balls would seem to be most free from this difficulty. Balls of about 3/8 in. diameter have been known to wear down as much as 1/32 in. in diameter in a few months and with a very small quantity of abrasive, such as emery dust, present.

Foreign particles, whether abrasive or not, have another detrimental effect on ball bearings. There is almost no clearance radially between the balls and races of ball bearings. Solid particles that are rolled between the balls and races are not only crushed but usually are indented into the material of the balls and raceways, because of the great unit pressures. The load-carrying capacity of these surfaces thus becomes impaired and the roughness results in a bearing noise.

Dirt is difficult to remove from a ball bearing. Even washing in a vessel of solvent will not usually remove all of it. When dirt mixes with the grease of a ball bearing there is no way of getting rid of it except by removing the contaminated grease.

**Speed.** The question of speed pronouncedly affects ball bearings. For one thing the bearing is artificially loaded by the centrifugal force of the balls moving at the high speeds. Tables of bearing load capacities, found in ball bearing catalogs, indicate the large percentage reductions in external loading that must be made when going from low to high speeds. Likewise, they also show that this problem is more critical as the larger sizes of bearings are considered so that an upper speed limit is set.

Roller bearings particularly are difficult to lubricate successfully at high speeds. In some cases the necessity of periodic replacement must be accepted as regular procedure. The use of oil instead of grease usually raises the upper limit for speed.

**Replacing ball bearings.** Another important consideration in connection with ball and roller bearings is the matter of fit. Involved in this is the engagement of inner race with the shaft, fit of the outer race in the housing bore, and the internal "fit-up" of the bearing, which determines the running clearances between the relative moving parts. The total radial clearance between balls and races of a ball bearing may be as little as a fifth or a tenth of the thickness of a human hair. The degree of internal looseness is held to close limits of accuracy by so-called selective assembly in which races are sorted according to diameter to tenths of a thousandth of an inch.

Balls likewise are sorted according to diameter to the same limits. Outer races, inner races and balls are then matched so that the required looseness will be obtained. Were it possible to continue this selective assembly when the bearings are mounted on the shaft and in the housing, less difficulty would be encountered.

The standard SAE ball bearing bore tolerances vary from about 0.0004 for small bearings of about 1 in. bore to twice this amount for larger bearings. The tolerance on the shaft diameter at the bearing fit for a bearing of average size will usually be about 0.005 in., with a minimum diameter to obtain a minimum interference fit of a tenth or two when the largest bore bearing is used.

When the largest shaft and smallest bore bearing get together the interference may become as much as 0.0010 on small bearings (1–2 in. bore) and 0.0015 on larger bearings, and a large percentage of this appears as increase in diameter of the inner race. If the internal clearance in the bearing is less than this, artificial loading of the bearings will take place. The balls will be slightly flattened and the races slightly dented. This flexing of the material travels around the balls and raceways with resultant heating of the bearing and failure of the surface material.

Similarly the fit of the outer race in the housing will not be uniform. The SAE tolerance for outer race outside diameter is 0.0005 in. for small bearings and as much as 0.0012 in. for large bearings. In good machining practice the bores of average size housings may be held to 0.001 to 0.0012 tolerance.

Because the shaft of a motor gets hotter than the frame structure it expands more in length. To compensate for this at least one bearing must be free to move axially in the housing and must have therefore a minimum of a few tenths of a thousandth clearance. Considering tolerances, the loosest fit may be as much as 0.003 in. This sometimes gives rise to objectionable noise.

## KINGSBURY THRUST BEARINGS

The Kingsbury thrust bearing is an oil bearing, suitable for either vertical or horizontal shafts. A plain collar forms one bearing member and pivoted segments form the other.

The segments, or shoes as they are commonly called, are mounted in various ways, but in all cases so as to be free to tilt both radially and tangentially as required by the operating conditions. The number of shoes depends upon the size and duty of the bearing.

The Kingsbury thrust bearing is so designed as to use the principles of fluid lubrication developed by Prof. Osborne Reynolds and described under sleeve bearings.

When the bearing is in operation, the bearing faces are separated by the oil film so that there is no metallic contact. The oil film forms automatically when the bearing begins to turn, and is maintained by movement of the bearing. The bearing faces of the shoes take an inclined position so that the oil film between the shoes and the collar are wedge shaped, the thin end pointing in the direction of rotation.

In a vertical installation, the bearing is usually mounted in a pot of oil. Rotation of the collar or runner maintains circulation of the oil, thus carrying the heat from the wedge shaped film. This heat is then dissipated from the outer surface of the container or is carried away through cooling coils.

When the shaft is at rest, with load on the thrust bearing, which is the case with vertical shafts, the oil film is not present and the coefficient of starting friction is high, averaging about .15. At the instance of starting and stopping, there is some rubbing between the metals but as the full area of the shoes bears against the collar or runner, the bearing is able to start without heating.

The rubbing of the metallic parts lasts about ¼ of a turn of the shaft, the oil film increasing with the speed. In some vertical machines this rubbing can be distinctly heard and there is noticeable vibration.

Horizontal thrust bearings such as are often used in steam turbines, are usually arranged for use with pressure lubricating systems.

Established lubrication practice for sleeve bearings applies in general for Kingsbury bearings, and the same operating caution should be used. For low speeds and heavy loads a heavy oil should be used, while for high speeds and moderate loads a light oil is preferable. Using a heavy oil at high speed increases the power loss in the bearing.

In general, Kingsbury thrust bearings are electrically insulated to prevent damage from bearing currents.

# XI

# TABLES AND OTHER USEFUL INFORMATION

The definitions, formulas, tables and other information that follow will be found very useful to the marine engineer and electrician in the daily jobs of operation, maintenance and repair of electrical equipment. As a collection of fundamental facts about electricity the chapter will also be a helpful reference guide when studying other sections of the book.

## COMMON ELECTRICAL TERMS

**Ampere** = Unit of current or rate of flow of electricity
**Volt** = Unit of electro-motive force
**Ohm** = Unit of Resistance

$$\text{Ohms Law; Current} = \frac{\text{Electro-Motive Force}}{\text{Resistance}}$$

**Megohm** = 1,000,000 Ohms
**Volt Amperes** or VA = Unit of apparent power
**Watt** = Unit of true power = VA × Power Factor
**Watthour** = Unit of electrical work and is employed to indicate the expenditure of an electrical power of one watt for one hour.
**Power Factor** = Ratio of true to apparent power
**Torque** (in ft. lb.) = Turning force represented by 1 lb. at radius 1 ft.
**Horsepower** is a measure of the time rate of doing work and is defined as the equivalent of raising 33,000 pounds one foot in one minute. One HP = 746 watts.
**Efficiency** is the ratio of the useful "output" of a machine to its total "input."

## EQUIVALENT VALUES IN DIFFERENT UNITS

### Kilowatt =

| | |
|---:|---|
| 1,000 | watts |
| 1.34 | HP |
| 2,655,000 | ft. lb. per hour |
| 44,260 | ft. lb. per minute |
| 737.3 | ft. lb. per second |
| 3,412 | heat-units per hour |
| 56.9 | heat-units per minute |
| .948 | heat-units per second |
| .2275 | lb. carbon oxidized per hour |
| 3.53 | lb. water evaporated per hour from and at 212° F. |

### Kilowatt-hour =

| | |
|---:|---|
| 1,000 | watthours |
| 1.34 | HP hours |
| 2,655,000 | ft. lb. |
| 3,600,000 | joules |
| 3,412 | heat-units (B.t.u.) |
| 367,000 | kg-m. |
| .235 | lb. carbon oxidized with perfect efficiency |
| 3.53 | lb. water evaporated from and at 212° F. |
| 22.75 | lb. water raised from 62° to 212° F. |

### 1 Horsepower =

746 watts
.746 kilowatts
33,000 ft. lb. per minute
550 ft. lb. per second
2,545 heat-units per hour
42.4 heat-units per minute
.707 heat-units per second
.175 lb. carbon oxidized per hour
2.64 lb. water evaporated per hour from and at 212° F.

### 1 Foot-pound =

1.356 joules
.1383 kg-m.
.000000377 kw-hr.
.001285 heat-unit
.0000005 HP-hour

### 1 Heat Unit =

1055 watt seconds
778 ft. lb.
107.6 kg-m.
.000293 kw-hr.
.000393 HP-hr.
.0000688 lb. carbon oxidized
1001036 lb. water evaporated from and at 212° F.

### 1 Heat Unit per sq. ft. per min. =

.122 watt per sq. in.
.0176 kw. per sq. ft.
.0236 HP per sq. ft.

### 1 Watt per sq. in. =

8.19 heat units per sq. ft. per min.
6,371 ft. lb. per sq. ft. per min.
.193 HP per sq. ft.

### 1 lb. Water Evaporated from and at 212° F. =

.283 kw-hr.
.379 HP-hr.
965.7 heat-units
103,900 kg-m.
1,019,000 joules
751,300 ft. lb.
.0664 lb. of carbon oxidized

### 1 Horsepower-hour =

.746 kw. hours
1,980,000 ft. lb.
2,545 heat-units
273,000 kg-m.
.175 carbon oxidized with perfect efficiency
2.64 lb. water evaporated from and at 212° F.
17.0 lb. water raised from 62° to 212° F.

### 1 Joule =

1 watt second
.000000278 kw-hr.
.102 kg-m.
.000948 heat-units
.7373 ft. lb.

### 1 Kilogram-meter =

7.233 ft. lb.
.00000365 HP-hour
.00000272 kw-hr.
.0093 heat-unit

### 1 Watt =

1 joule per second
.00134 HP
3412 heat-units per hour
.7373 ft. lb. per second
.0035 lb. water evaporated per hour
44.24 ft. lb. per minute

### 1 lb. Carbon Oxidized with Perfect Efficiency =

14,544 heat-units
1.11 lb. anthracite coal oxidized
2.5 lb. dry wood oxidized
21 cu. ft. illuminating gas
4.26 kw-hr.
5.71 HP-hr.
1,315,000 ft. lb.
15 lb. water evaporated from and at 212° F.

### 1 B.t.u. (British Thermal Unit) =

778 foot-pounds
17.452 wattminutes
0.293 watthour
Latent heat of evaporation of water = 966 B.t.u.
Latent heat of melting of water = 142 B.t.u.

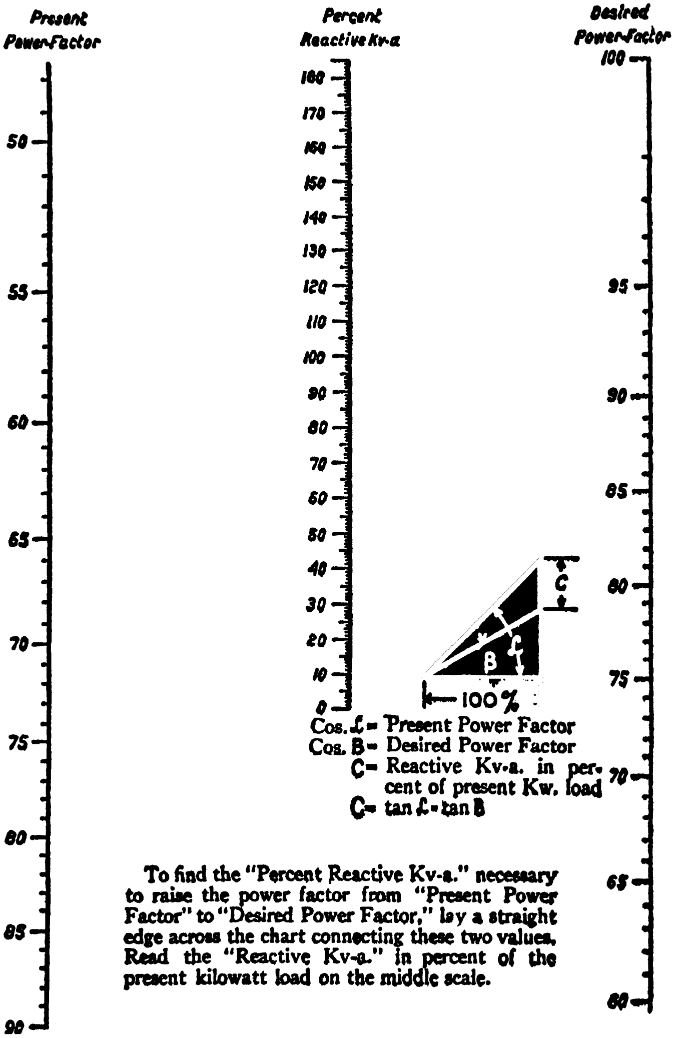
## CONVERSION FACTORS

| To Convert | Multiply By |
|---|---|
| **Area** | |
| Circular Mils to Square Inches | .0000007854 |
| Circular Mils to Square Mils | .7854 |
| Circular Mils to Square Millimeters | .0005066 |
| Square Centimeters to Square Inches | .155 |
| Square Feet to Square Meters | .0929 |
| Square Inches to Circular Mils | 1,743,240. |
| Square Inches to Square Centimeters | 6.4516 |
| Square Inches to Square Millimeters | 645.16 |
| Square Meters to Square Feet | 10.764 |
| Square Inches to Square Mils | 1,000,000. |
| Square Millimeters to Square Inches | .00155 |
| Square Millimeters to Circular Mils | 1,973.51 |
| Square Mils to Circular Mils | 1.2732 |
| Square Mils to Square Inches | .000001 |
| **Length** | |
| Centimeters to Inches | .3937 |
| Centimeters to Feet | .03281 |
| Feet to Centimeters | 30.48 |
| Feet to Meters | .3048 |
| Inches to Centimeters | 2.54 |
| Inches to Meters | .0254 |
| Inches to Millimeters | 25.4 |
| Inches to Mils | 1,000. |
| Kilometers to Miles | .6214 |
| Meters to Feet | 3.2808 |
| Meters to Inches | 39.3701 |
| Meters to Yards | 1.0936 |
| Miles to Kilometers | 1.6093 |
| Millimeters to Inches | .03937 |
| Millimeters to Mils | 39.3701 |
| Mils to Inches | .001 |
| Mils to Millimeters | .0254 |
| Yards to Meters | .9144 |
| **Power** | |
| Foot Pounds per Minute to Horsepower | .0000303 |
| Foot Pounds per Minute to Watts | .0226 |
| Foot Pounds per Second to Horsepower | .001818 |
| Foot Pounds per Second to Watts | 1.356 |
| Horsepower to Foot Pounds per Minute | 33,000. |

| | |
|---|---|
| Horsepower to Foot Pounds per Second | 550. |
| Horsepower to Watts | 746. |
| Kilogram Meters per Second to Watts | 9.807 |
| Watts to Foot Pounds per Minute | 44.25 |
| Watts to Foot Pounds per Second | .7375 |
| Watts to Horsepower | .001341 |
| Watts to Kilogram-meters per Second | .1020 |
| **Energy** | |
| British Thermal Units to Foot Pounds | 778. |
| British Thermal Units to Joules | 1,055. |
| British Thermal Units to Watthours | .293 |
| Foot Pounds to British Thermal Units | .001285 |
| Foot Pounds to Joules | 1.356 |
| Foot Pounds to Kilogram-meters | .1383 |
| Gram Calories to Joules | 4.186 |
| Joules to British Thermal Units | .000947 |
| Joules to Foot Pounds | .7375 |
| Joules to Gram-Calories | .2388 |
| Joules to Kilogram-meters | .10198 |
| Kilogram-meters to Foot Pounds | 7.233 |
| Kilogram-meters to Joules | 9.8117 |
| Watthours to British Thermal Units | 3.4126 |
| **Miscellaneous** | |
| Kilograms to Pounds | 2.205 |
| Kilograms per Kilometer to Pounds per 1000 Feet | .6719 |
| Ohms per Kilometer to Ohms per 1000 Feet | .3048 |
| Ohms per 1000 Feet to Ohms per Kilometer | 3.2808 |
| Ohms per 1000 Yards to Ohms per Kilometer | 1.0936 |
| Pounds to Kilograms | .4536 |
| Pounds per 1000 Feet to Kilograms per Kilometer | 1.488 |
| Pounds per 1000 Yards to Kilograms per Kilometer | .4960 |
| Pounds per 1000 Yards to Pounds per Kilometer | 1.0936 |

# EQUIVALENTS OF AN INCH

| Fraction | Decimal | Millimeters | Fraction | Decimal | Millimeters |
|---|---|---|---|---|---|
| 1/64 | .015625 | 0.397 | 33/64 | .515625 | 13.097 |
| 1/32 | .031250 | 0.794 | 17/32 | .531250 | 13.494 |
| 3/64 | .046875 | 1.191 | 35/64 | .546875 | 13.891 |
| 1/16 | .062500 | 1.588 | 9/16 | .562500 | 14.288 |
| 5/64 | .078125 | 1.984 | 37/64 | .578125 | 14.684 |
| 3/32 | .093750 | 2.381 | 19/32 | .593750 | 15.081 |
| 7/64 | .109375 | 2.778 | 39/64 | .609375 | 15.478 |
| 1/8 | .125000 | 3.175 | 5/8 | .625000 | 15.875 |
| 9/64 | .140625 | 3.572 | 41/64 | .640625 | 16.272 |
| 5/32 | .156250 | 3.969 | 21/32 | .656250 | 16.669 |
| 11/64 | .171875 | 4.366 | 43/64 | .671875 | 17.066 |
| 3/16 | .187500 | 4.763 | 11/16 | .687500 | 17.463 |
| 13/64 | .203125 | 5.159 | 45/46 | .703125 | 17.859 |
| 7/32 | .218750 | 5.556 | 23/32 | .718750 | 18.256 |
| 15/64 | .234375 | 5.953 | 47/64 | .734375 | 18.653 |
| 1/4 | .250000 | 6.350 | 3/4 | .750000 | 19.050 |
| 17/64 | .265625 | 6.747 | 49/64 | .765625 | 19.447 |
| 9/32 | .281250 | 7.144 | 25/32 | .781250 | 19.844 |
| 19/64 | .296875 | 7.541 | 51/64 | .796875 | 20.241 |
| 5/16 | .312500 | 7.938 | 13/16 | .812500 | 20.638 |
| 21/64 | .328125 | 8.334 | 53/64 | .828125 | 21.034 |
| 11/32 | .343750 | 8.731 | 27/32 | .843750 | 21.431 |
| 23/64 | .359375 | 9.128 | 55/64 | .859375 | 21.828 |
| 3/8 | .375000 | 9.525 | 7/8 | .875000 | 22.225 |
| 25/64 | .390625 | 9.922 | 57/64 | .890625 | 22.622 |
| 13/32 | .406250 | 10.319 | 29/32 | .906250 | 23.019 |
| 27/64 | .421875 | 10.716 | 59/64 | .921875 | 23.416 |
| 7/16 | .437500 | 11.113 | 15/16 | .937500 | 23.813 |
| 29/64 | .453125 | 11.509 | 61/64 | .953125 | 24.209 |
| 15/32 | .468750 | 11.906 | 31/32 | .968750 | 24.606 |
| 31/64 | .484375 | 12.303 | 63/64 | .984375 | 25.003 |
| 1/2 | .500000 | 12.700 | 1 | 1.000000 | 25.400 |



Cos. A = Present Power Factor
Cos. B = Desired Power Factor
C = Reactive Kv-a. in per-cent of present Kw. load
C = tan A - tan B

To find the "Percent Reactive Kv-a." necessary to raise the power factor from "Present Power Factor" to "Desired Power Factor," lay a straight edge across the chart connecting these two values. Read the "Reactive Kv-a." in percent of the present kilowatt load on the middle scale.

FIG. 97. Handy chart for finding per cent reactive Kv-a. (Copyrighted 1921, Westinghouse Electric & Mfg. Co. W. E. Douglass 11-26-21.)

## HANDY FORMULAE

**Power Transmission by Shaft**

$$HP = \frac{\text{Torque (in ft. lb.)} \times \text{r.p.m.}}{5250}$$

**Hydraulics.** HP of Water Fall = .114 × cu. ft. per sec. × head in ft. × Eff. Assuming 88 per cent eff. of water wheel, then:

100 cu. ft. per sec. with 10 ft. head = 100 HP.

**Power to Drive Pumps**

$$HP = \frac{\text{Gal. per min.} \times \text{Total head (inc. friction)}}{3960 \times \text{Eff. of Pump}}$$

**Fans and Blowers**

$$\text{HP to drive fans} = \frac{K \times \text{cu. ft. min.} \times \text{water gage pressure in in.}}{33{,}000 \times \text{Eff. of fan}}$$

Water gage inches = 1.728 oz. per sq. in.

$K = 5.2$

Eff. = .5 for ordinary fans to .65 for Sirocco type

**Rotating Mass Formulas.** Useful in estimating time to start—stop or change speed of flywheels, motors, etc. with certain applied torque =

$$\text{Time (Sec.)} = \frac{WR^2 \times \text{change in r.p.m.}}{322 \times \text{torque (ft. lb.)}}$$

## MENSURATION OF SURFACES AND VOLUMES

**Area of Rectangle** = length × breadth.

**Area of Triangle** = ½ base × perpendicular height.

**Circumference of Circle** = diameter × 3.1416.

**Area of Circle** = square of diameter × .7854.

**To Find Diameter of a Circle of Given Area**

Divide area by .7854 and extract square root.

**To Find Volume of a Cylinder**

Area of section in square inches × length in inches = Volume in cubic inches.

**Cubic inches ÷ 1728** = Volume in cubic feet.

**Surface of a Sphere** = Square of diam. × 3.1416.

**Volume of a Sphere** = Cube of diam. × .5236.

**Diameter × .8862** = Side of square of equal area.

**Diameter × .7071** = Side of inscribed square.

**Circumference** = $3.5449 \times \sqrt{\text{area of circle.}}$

**Diameter** = $1.1284 \times \sqrt{\text{area of circle.}}$

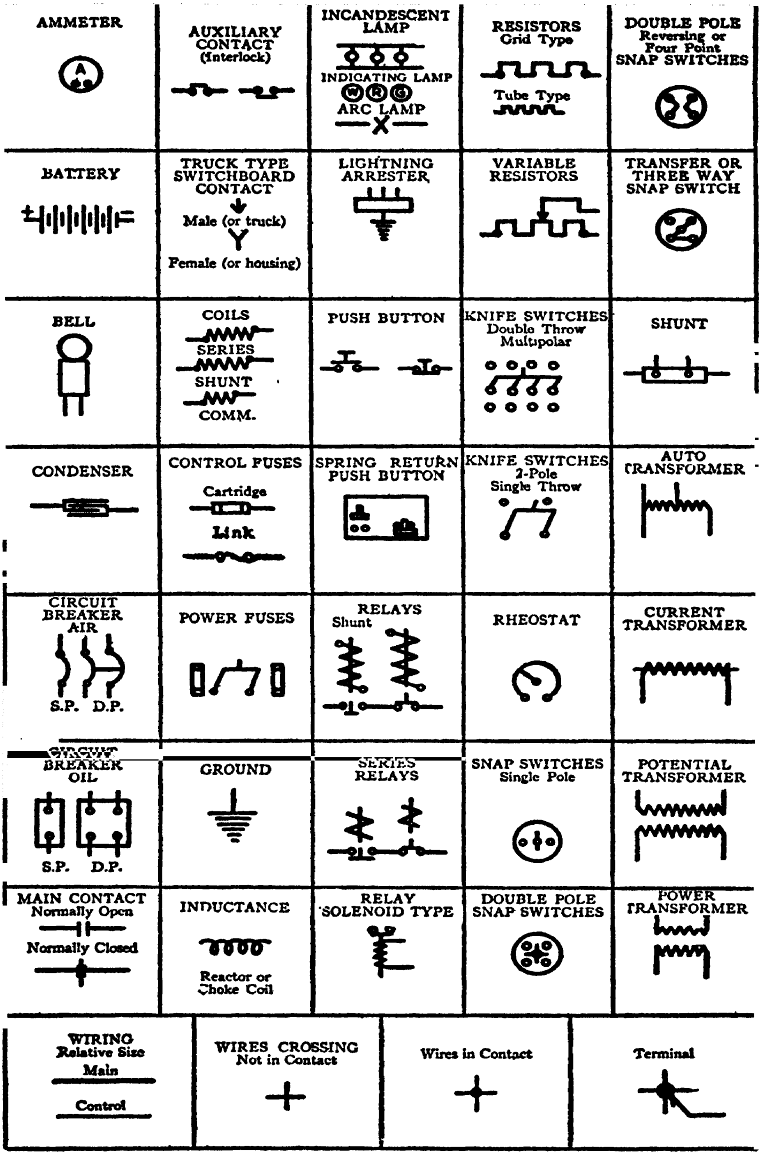


FIG. 98. Electricity graphic symbols.

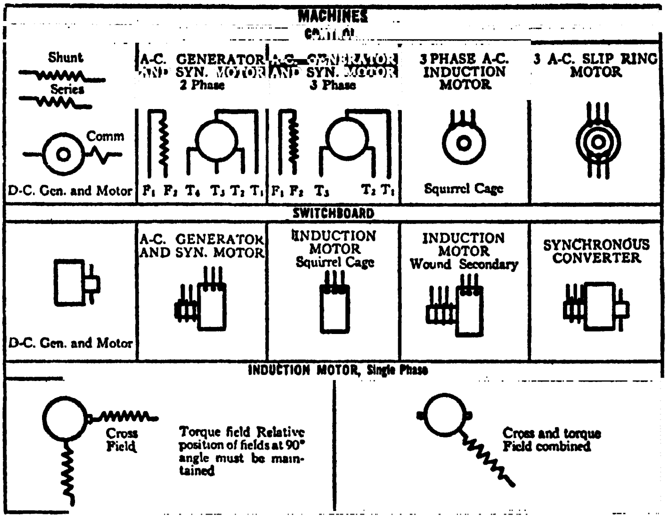

MACHINES
Shunt
Series
Comm
D-C. Gen. and Motor
A-C. GENERATOR AND SYN. MOTOR 2 Phase
$F_1$ $F_2$ $T_4$ $T_3$ $T_2$ $T_1$
A-C. GENERATOR AND SYN. MOTOR 3 Phase
$F_1$ $F_2$ $T_3$ $T_2$ $T_1$
3 PHASE A-C. INDUCTION MOTOR
Squirrel Cage
3 A-C. SLIP RING MOTOR
SWITCHBOARD
D-C. Gen. and Motor
A-C. GENERATOR AND SYN. MOTOR
INDUCTION MOTOR Squirrel Cage
INDUCTION MOTOR Wound Secondary
SYNCHRONOUS CONVERTER
INDUCTION MOTOR, Single Phase
Cross Field
Torque field Relative position of fields at 90° angle must be maintained
Cross and torque Field combined

FIG. 99. Electrical machinery graphic symbols.

## GAGES—WIRE AND SHEET METAL

| Abbreviation | Name | Principal Applications |
|---|---|---|
| AWG or B&S | American Standard Wire Gage also known as Brown & Sharpe Gage | Non-Ferrous Wire, sheet and strap. Steel banding wire. |
| BWG | Birmingham Wire Gage also known as Stubs' Iron Wire Gage. | Spring steel (narrow strips). Wall tks. of seamless metal tubing. |
| Stl. WG or NWG | Steel Wire Gage also known as National, Roebling's, or Washburn and Moen's Wire Gage. | Steel wire except music wire and banding wire. |
| USG | United States Standard Gage. | Iron & Steel Sheet. The table shown uses the U. S. Standard Gage iron values for both iron and steel sheet. |
| MWG | Music Wire Gage. | Steel spring wire .090 diam. and less. |

# GAGE SIZE TABLE

| GAGE No. | AWG (B&S) | BWG | Stl. WG (NWG) | USG | MWG |
|---|---|---|---|---|---|
| 0000000 | . | | .490 | .500 | . |
| 000000 | . | . | .462 | .469 | . . |
| 00000 | . . | . . . . | .431 | .438 | |
| 0000 | .460 | .454 | .394 | .406 | . . |
| 000 | .410 | .425 | .363 | .375 | . . . . |
| 00 | .365 | .380 | .331 | .344 | .0085 |
| 0 | .325 | .340 | .307 | .313 | .009 |
| 1 | .289 | .300 | .283 | .281 | .010 |
| 2 | .258 | .284 | .263 | .266 | .011 |
| 3 | .229 | .259 | .244 | .250 | .012 |
| 4 | .204 | .238 | .225 | 234 | .013 |
| 5 | .182 | .220 | .207 | .219 | .014 |
| 6 | .162 | .203 | 192 | .203 | .016 |
| 7 | .144 | .180 | .177 | .188 | .018 |
| 8 | .129 | .165 | .162 | .172 | .020 |
| 9 | .114 | .148 | .148 | .156 | .022 |
| 10 | .102 | .134 | .135 | .141 | .024 |
| 11 | .091 | .120 | .121 | .125 | .026 |
| 12 | .081 | .109 | .106 | .109 | .028 |
| 13 | .072 | .095 | .0915 | .0938 | .030 |
| 14 | .064 | .083 | .0800 | .0781 | .032 |
| 15 | .057 | .072 | .0720 | .0703 | .034 |
| 16 | .051 | .065 | .0625 | .0625 | .036 |
| 17 | .045 | .058 | .0540 | .0563 | .038 |
| 18 | .040 | .049 | .0475 | .0500 | .040 |
| 19 | .036 | .042 | .0410 | .0438 | .042 |
| 20 | .032 | .035 | .0348 | .0375 | .044 |
| 21 | .0285 | .032 | .0317 | .0344 | .046 |
| 22 | .0254 | .028 | .0286 | .0313 | .048 |
| 23 | .0226 | .025 | .0258 | .0281 | .051 |
| 24 | .0201 | .022 | .0230 | .0250 | .055 |
| 25 | .0179 | .020 | .0204 | .0219 | .059 |
| 26 | .0159 | .018 | .0181 | .0188 | .063 |
| 27 | .0142 | .016 | .0173 | .0172 | .067 |
| 28 | .0126 | .014 | .0162 | .0156 | .071 |
| 29 | .0113 | .013 | .0150 | .0141 | .074 |
| 30 | .0100 | .012 | .0140 | .0125 | .078 |
| 31 | .0089 | .010 | .0132 | .0109 | .082 |
| 32 | .0080 | .009 | .0128 | .0102 | .086 |
| 33 | .0071 | .008 | .0118 | .0094 | .090 |
| 34 | .0063 | .007 | .0104 | .0086 | . . . . |
| 35 | .0056 | .005 | .0095 | .0078 | . . . . |
| 36 | .0050 | .004 | .0090 | .0070 | . . . . |

## GAGE SIZE TABLE (*Concluded*)

| GAGE No | AWG (B&S) | BWG | Stl WG (NWG) | USG | MWG |
|---|---|---|---|---|---|
| 37 | 0045 | | 0085 | 0066 | |
| 38 | 0040 | | 0080 | 0063 | |
| 39 | 0035 | | 0075 | | |
| 40 | 0031 | | 0070 | | |
| 41 | 0028 | | 0066 | | |
| 42 | 0025 | | 0062 | | |
| 43 | 0022 | | 0060 | | |
| 44 | 0020 | | 0058 | | |
| 45 | 0018 | | 0055 | | |
| 46 | 0016 | | 0052 | | |
| 47 | 0014 | | 0050 | | |
| 48 | 0012 | | 0048 | | |
| 49 | 0011 | | 0046 | | |
| 50 | 0010 | | 0044 | | |

Gage equivalents shown are rounded values —This table is for reference only

## DETERMINATION OF TEMPERATURE

### by Resistance Measurements

Based on a temperature coefficient for copper wire of .00427 at 0° C, the following relations exist between resistance and temperature.

$R =$ Resistance of winding at T° C (final temp )
$r =$ Resistance of winding at t° C. (initial temp.)
then·

$$R \div r = (234\ 5 + T) \div (234\ 5 + t)$$

or.

$$T = R \div r \times (234\ 5 + t) - 234\ 5$$

# TEMPERATURE CONVERSION TABLES *

by Albert Sauveur

## 0 to 100

| C. | | F. | C. | | F. |
|---|---|---|---|---|---|
| −17.8 | **0** | 32 | 10.0 | **50** | 122.0 |
| −17.2 | **1** | 33.8 | 10.6 | **51** | 123.8 |
| −16.7 | **2** | 35.6 | 11.1 | **52** | 125.6 |
| −16.1 | **3** | 37.4 | 11.7 | **53** | 127.4 |
| −15.6 | **4** | 39.2 | 12.2 | **54** | 129.2 |
| −15.0 | **5** | 41.0 | 12.8 | **55** | 131.0 |
| −14.4 | **6** | 42.8 | 13.3 | **56** | 132.8 |
| −13.9 | **7** | 44.6 | 13.9 | **57** | 134.6 |
| −13.3 | **8** | 46.4 | 14.4 | **58** | 136.4 |
| −12.8 | **9** | 48.2 | 15.0 | **59** | 138.2 |
| −12.1 | **10** | 50.0 | 15.6 | **60** | 140.0 |
| −11.7 | **11** | 51.8 | 16.1 | **61** | 141.8 |
| −11.1 | **12** | 53.6 | 16.7 | **62** | 143.6 |
| −10.6 | **13** | 55.4 | 17.2 | **63** | 145.4 |
| −10.0 | **14** | 57.2 | 17.8 | **64** | 147.2 |
| − 9.44 | **15** | 59.0 | 18.3 | **65** | 149.0 |
| − 8.89 | **16** | 60.8 | 18.9 | **66** | 150.8 |
| − 8.33 | **17** | 62.6 | 19.4 | **67** | 152.6 |
| − 7.78 | **18** | 64.4 | 20.0 | **68** | 154.4 |
| − 7.22 | **19** | 66.2 | 20.6 | **69** | 156.2 |
| − 6.67 | **20** | 68.0 | 21.1 | **70** | 158.0 |
| − 6.11 | **21** | 69.8 | 21.7 | **71** | 159.8 |
| − 5.56 | **22** | 71.6 | 22.2 | **72** | 161.6 |
| − 5.00 | **23** | 73.4 | 22.8 | **73** | 163.4 |
| − 4.44 | **24** | 75.2 | 23.3 | **74** | 165.2 |
| − 3.89 | **25** | 77.0 | 23.9 | **75** | 167.0 |
| − 3.33 | **26** | 78.8 | 24.4 | **76** | 168.8 |
| − 2.78 | **27** | 80.6 | 25.0 | **77** | 170.6 |
| − 2.22 | **28** | 82.4 | 25.6 | **78** | 172.4 |
| − 1.67 | **29** | 84.2 | 26.1 | **79** | 174.2 |
| − 1.11 | **30** | 86.0 | 26.7 | **80** | 176.0 |
| − 0.56 | **31** | 87.8 | 27.2 | **81** | 177.8 |
| 0 | **32** | 89.6 | 27.8 | **82** | 179.6 |
| 0.56 | **33** | 91.4 | 28.3 | **83** | 181.4 |
| 1.11 | **34** | 93.2 | 28.9 | **84** | 183.2 |
| 1.67 | **35** | 95.0 | 29.4 | **85** | 185.0 |
| 2.22 | **36** | 96.8 | 30.0 | **86** | 186.8 |
| 2.78 | **37** | 98.6 | 30.6 | **87** | 188.6 |
| 3.33 | **38** | 100.4 | 31.1 | **88** | 190.4 |
| 3.89 | **39** | 102.2 | 31.7 | **89** | 192.2 |
| 4.44 | **40** | 104.0 | 32.2 | **90** | 194.0 |
| 5.00 | **41** | 105.8 | 32.8 | **91** | 195.8 |
| 5.56 | **42** | 107.6 | 33.3 | **92** | 197.6 |

## 0 to 100 -Cont.

| C. | | F. | C. | | F. |
|---|---|---|---|---|---|
| 6.11 | **43** | 109.4 | 33.9 | **93** | 199.4 |
| 6.67 | **44** | 111.2 | 34.4 | **94** | 201.2 |
| 7.22 | **45** | 113.0 | 35.0 | **95** | 203.0 |
| 7.78 | **46** | 114.8 | 35.6 | **96** | 204.8 |
| 8.33 | **47** | 116.6 | 36.1 | **97** | 206.6 |
| 8.89 | **48** | 118.4 | 36.7 | **98** | 208.4 |
| 9.44 | **49** | 120.2 | 37.2 | **99** | 210.2 |
| | | | 37.8 | **100** | 212.0 |

## 100 to 1000

| C. | | F. | C. | | F. |
|---|---|---|---|---|---|
| 38 | **100** | 212 | 260 | **500** | 932 |
| 43 | **110** | 230 | 266 | **510** | 950 |
| 49 | **120** | 248 | 271 | **520** | 968 |
| 54 | **130** | 266 | 277 | **530** | 986 |
| 60 | **140** | 284 | 282 | **540** | 1004 |
| 66 | **150** | 302 | 288 | **550** | 1022 |
| 71 | **160** | 320 | 293 | **560** | 1040 |
| 77 | **170** | 338 | 299 | **570** | 1058 |
| 82 | **180** | 356 | 304 | **580** | 1076 |
| 88 | **190** | 374 | 310 | **590** | 1094 |
| 93 | **200** | 392 | 316 | **600** | 1112 |
| 99 | **210** | 410 | 321 | **610** | 1130 |
| 100 | **212** | 413 | 327 | **620** | 1148 |
| 104 | **220** | 428 | 332 | **630** | 1166 |
| 110 | **230** | 446 | 338 | **640** | 1184 |
| 116 | **240** | 464 | 343 | **650** | 1202 |
| 121 | **250** | 482 | 349 | **660** | 1220 |
| 127 | **260** | 500 | 354 | **670** | 1238 |
| 132 | **270** | 518 | 360 | **680** | 1256 |
| 138 | **280** | 536 | 366 | **690** | 1274 |
| 143 | **290** | 554 | 371 | **700** | 1292 |
| 149 | **300** | 572 | 377 | **710** | 1310 |
| 154 | **310** | 590 | 382 | **720** | 1328 |
| 160 | **320** | 608 | 388 | **730** | 1346 |
| 166 | **330** | 626 | 393 | **740** | 1364 |
| 171 | **340** | 644 | 399 | **750** | 1382 |
| 177 | **350** | 662 | 404 | **760** | 1400 |
| 182 | **360** | 680 | 410 | **770** | 1418 |
| 188 | **370** | 698 | 416 | **780** | 1436 |
| 193 | **380** | 716 | 421 | **790** | 1454 |
| 199 | **390** | 734 | 427 | **800** | 1472 |

### 100 to 1000—Cont

| C | | F | C | | F |
|---|---|---|---|---|---|
| 204 | **400** | 752 | 432 | **810** | 1490 |
| 210 | **410** | 770 | 438 | **820** | 1508 |
| 216 | **420** | 788 | 443 | **830** | 1526 |
| 221 | **430** | 806 | 449 | **840** | 1544 |
| 227 | **440** | 824 | 454 | **850** | 1562 |
| 232 | **450** | 842 | 460 | **860** | 1580 |
| 238 | **460** | 860 | 466 | **870** | 1598 |
| 243 | **470** | 878 | 471 | **880** | 1616 |
| 249 | **480** | 896 | 477 | **890** | 1634 |
| 254 | **490** | 914 | 482 | **900** | 1652 |
| | | | 488 | **910** | 1670 |
| | | | 493 | **920** | 1688 |
| | | | 499 | **930** | 1706 |
| | | | 504 | **940** | 1724 |
| | | | 510 | **950** | 1742 |
| | | | 516 | **960** | 1760 |
| | | | 521 | **970** | 1778 |
| | | | 527 | **980** | 1796 |
| | | | 532 | **990** | 1814 |
| | | | 538 | **1000** | 1832 |

### 1000 to 2000

| C | | F | C | | F |
|---|---|---|---|---|---|
| 538 | **1000** | 1832 | 816 | **1500** | 2732 |
| 543 | **1010** | 1850 | 821 | **1510** | 2750 |
| 549 | **1020** | 1868 | 827 | **1520** | 2768 |
| 554 | **1030** | 1886 | 832 | **1530** | 2786 |
| 560 | **1040** | 1904 | 838 | **1540** | 2804 |
| 566 | **1050** | 1922 | 843 | **1550** | 2822 |
| 571 | **1060** | 1940 | 849 | **1560** | 2840 |
| 577 | **1070** | 1958 | 854 | **1570** | 2858 |
| 582 | **1080** | 1976 | 860 | **1580** | 2876 |
| 588 | **1090** | 1994 | 866 | **1590** | 2894 |
| 593 | **1100** | 2012 | 871 | **1600** | 2912 |
| 599 | **1110** | 2030 | 877 | **1610** | 2930 |
| 604 | **1120** | 2048 | 882 | **1620** | 2948 |
| 610 | **1130** | 2066 | 888 | **1630** | 2966 |
| 616 | **1140** | 2084 | 893 | **1640** | 2984 |
| 621 | **1150** | 2102 | 899 | **1650** | 3002 |
| 627 | **1160** | 2120 | 904 | **1660** | 3020 |
| 632 | **1170** | 2138 | 910 | **1670** | 3038 |
| 638 | **1180** | 2156 | 916 | **1680** | 3056 |
| 643 | **1190** | 2174 | 921 | **1690** | 3074 |

### 1000 to 2000--Cont

| C | | F | C | | F. |
|---|---|---|---|---|---|
| 649 | **1200** | 2192 | 927 | **1700** | 3092 |
| 654 | **1210** | 2210 | 932 | **1710** | 3110 |
| 660 | **1220** | 2228 | 938 | **1720** | 3128 |
| 666 | **1230** | 2246 | 943 | **1730** | 3146 |
| 671 | **1240** | 2264 | 949 | **1740** | 3164 |
| 677 | **1250** | 2282 | 954 | **1750** | 3182 |
| 682 | **1260** | 2300 | 960 | **1760** | 3200 |
| 688 | **1270** | 2318 | 966 | **1770** | 3218 |
| 693 | **1280** | 2336 | 971 | **1780** | 3236 |
| 699 | **1290** | 2354 | 977 | **1790** | 3254 |
| 704 | **1300** | 2372 | 982 | **1800** | 3272 |
| 710 | **1310** | 2390 | 988 | **1810** | 3290 |
| 716 | **1320** | 2408 | 993 | **1820** | 3308 |
| 721 | **1330** | 2426 | 999 | **1830** | 3326 |
| 727 | **1340** | 2444 | 1004 | **1840** | 3344 |
| 732 | **1350** | 2462 | 1010 | **1850** | 3362 |
| 738 | **1360** | 2480 | 1016 | **1860** | 3380 |
| 743 | **1370** | 2498 | 1021 | **1870** | 3398 |
| 749 | **1380** | 2516 | 1027 | **1880** | 3416 |
| 754 | **1390** | 2534 | 1032 | **1890** | 3434 |
| 760 | **1400** | 2552 | 1038 | **1900** | 3452 |
| 766 | **1410** | 2570 | 1043 | **1910** | 3470 |
| 771 | **1420** | 2588 | 1049 | **1920** | 3488 |
| 777 | **1430** | 2606 | 1054 | **1930** | 3506 |
| 782 | **1440** | 2624 | 1060 | **1940** | 3524 |
| 788 | **1450** | 2642 | 1066 | **1950** | 3542 |
| 793 | **1460** | 2660 | 1071 | **1960** | 3560 |
| 799 | **1470** | 2678 | 1077 | **1970** | 3578 |
| 804 | **1480** | 2696 | 1082 | **1980** | 3596 |
| 810 | **1490** | 2714 | 1088 | **1990** | 3614 |
| | | | 1093 | **2000** | 3632 |

### 2000 to 3000

| C | | F | C | | F. |
|---|---|---|---|---|---|
| 1093 | **2000** | 3632 | 1371 | **2500** | 4532 |
| 1099 | **2010** | 3650 | 1377 | **2510** | 4550 |
| 1104 | **2020** | 3668 | 1382 | **2520** | 4568 |
| 1110 | **2030** | 3686 | 1388 | **2530** | 4586 |
| 1116 | **2040** | 3704 | 1393 | **2540** | 4604 |
| 1121 | **2050** | 3722 | 1399 | **2550** | 4622 |
| 1127 | **2060** | 3740 | 1404 | **2560** | 4640 |
| 1132 | **2070** | 3758 | 1410 | **2570** | 4658 |
| 1138 | **2080** | 3776 | 1416 | **2580** | 4676 |

2000 to 3000—Cont.

| C. | | F. | C. | | F. |
|---|---|---|---|---|---|
| 1143 | **2090** | 3794 | 1421 | **2590** | 4694 |
| 1149 | **2100** | 3812 | 1427 | **2600** | 4712 |
| 1154 | **2110** | 3830 | 1432 | **2610** | 4730 |
| 1160 | **2120** | 3848 | 1438 | **2620** | 4748 |
| 1166 | **2130** | 3866 | 1443 | **2630** | 4766 |
| 1171 | **2140** | 3884 | 1449 | **2640** | 4784 |
| 1177 | **2150** | 3902 | 1454 | **2650** | 4802 |
| 1182 | **2160** | 3920 | 1460 | **2660** | 4820 |
| 1188 | **2170** | 3938 | 1466 | **2670** | 4838 |
| 1193 | **2180** | 3956 | 1471 | **2680** | 4856 |
| 1199 | **2190** | 3974 | 1477 | **2690** | 4874 |
| 1204 | **2200** | 3992 | 1482 | **2700** | 4892 |
| 1210 | **2210** | 4010 | 1488 | **2710** | 4910 |
| 1216 | **2220** | 4028 | 1493 | **2720** | 4928 |
| 1221 | **2230** | 4046 | 1499 | **2730** | 4946 |
| 1227 | **2240** | 4064 | 1504 | **2740** | 4964 |
| 1232 | **2250** | 4082 | 1510 | **2750** | 4982 |
| 1238 | **2260** | 4100 | 1516 | **2760** | 5000 |
| 1243 | **2270** | 4118 | 1521 | **2770** | 5018 |
| 1249 | **2280** | 4136 | 1527 | **2780** | 5036 |
| 1254 | **2290** | 4154 | 1532 | **2790** | 5054 |
| 1260 | **2300** | 4172 | 1538 | **2800** | 5072 |
| 1266 | **2310** | 4190 | 1543 | **2810** | 5090 |
| 1271 | **2320** | 4208 | 1549 | **2820** | 5108 |
| 1277 | **2330** | 4226 | 1554 | **2830** | 5126 |

2000 to 3000—Cont.

| C. | | F. | C. | | F. |
|---|---|---|---|---|---|
| 1282 | **2340** | 4244 | 1560 | **2840** | 5144 |
| 1288 | **2350** | 4262 | 1566 | **2850** | 5162 |
| 1293 | **2360** | 4280 | 1571 | **2860** | 5180 |
| 1299 | **2370** | 4298 | 1577 | **2870** | 5198 |
| 1304 | **2380** | 4316 | 1582 | **2880** | 5216 |
| 1310 | **2390** | 4334 | 1588 | **2890** | 5234 |
| 1316 | **2400** | 4352 | 1593 | **2900** | 5252 |
| 1321 | **2410** | 4370 | 1599 | **2910** | 5270 |
| 1327 | **2420** | 4388 | 1604 | **2920** | 5288 |
| 1332 | **2430** | 4406 | 1610 | **2930** | 5306 |
| 1338 | **2440** | 4424 | 1616 | **2940** | 5324 |
| 1343 | **2450** | 4442 | 1621 | **2950** | 5342 |
| 1349 | **2460** | 4460 | 1627 | **2960** | 5360 |
| 1354 | **2470** | 4478 | 1632 | **2970** | 5378 |
| 1360 | **2480** | 4496 | 1638 | **2980** | 5396 |
| 1366 | **2490** | 4514 | 1643 | **2990** | 5414 |
| | | | 1649 | **3000** | 5432 |

INTERPOLATION FACTORS

| C. | | F. | C. | | F. |
|---|---|---|---|---|---|
| 0.56 | **1** | 1.8 | 3.33 | **6** | 10.8 |
| 1.11 | **2** | 3.6 | 3.89 | **7** | 12.6 |
| 1.67 | **3** | 5.4 | 4.44 | **8** | 14.4 |
| 2.22 | **4** | 7.2 | 5.00 | **9** | 16.2 |
| 2.78 | **5** | 9.0 | 5.56 | **10** | 18.0 |

Note.—The numbers in bold face type refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit degrees to Centigrade degrees, the equivalent temperature will be found in the left column; while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right.

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## WIRE SIZES FOR MOTOR CIRCUITS

### I. Single-Phase AC Motors. Amperes at Full Load.

| HP | 110V | 220V * | 440V | HP | 110V | 220V * | 440V |
|---|---|---|---|---|---|---|---|
| ⅙ | 3.34 | 1.67 | | 2 | 20 | 10 | |
| ¼ | 4.8 | 2.4 | | 3 | 28 | 14 | |
| ½ | 7 | 3.5 | | 5 | 46 | 23 | |
| ¾ | 9.4 | 4.7 | | 7½ | 68 | 34 | 17 |
| 1 | 11 | 5.5 | | 10 | 86 | 43 | 21.5 |
| 1½ | 15.2 | 7.6 | | | | | |

### II. Two-Phase AC Motors (4-Wire). Amperes at Full Load.

| | Induction Type Squirrel-Cage and Wound Rotor | | | | | Synchronous Type Unity Power Factor | | | |
|---|---|---|---|---|---|---|---|---|---|
| HP | 110V | 220V | 440V | 550V | 2200 V | 220V | 440V | 550V | 2200 V |
| ½ | 4.3 | 2.2 | 1.1 | .9 | | | | | |
| ¾ | 4.7 | 2.4 | 1.2 | 1.0 | | | | | |
| 1 | 5.7 | 2.9 | 1.4 | 1.2 | | | | | |
| 1½ | 7.7 | 4.0 | 2 | 1.6 | | | | | |
| 2 | 10.4 | 5 | 3 | 2.0 | | | | | |
| 3 | | 6 | 4 | 3.0 | | | | | |
| 5 | | 13 | 7 | 6 | | | | | |
| 7½ | | 19 | 9 | 7 | | | | | |
| 10 | | 24 | 12 | 10 | | | | | |
| 15 | | 33 | 16 | 13 | | | | | |
| 20 | | 45 | 23 | 19 | | | | | |
| 25 | | 55 | 28 | 22 | 6 | 47 | 24 | 19 | 4.7 |
| 30 | | 67 | 34 | 27 | 7 | 56 | 29 | 23 | 5.7 |
| 40 | | 88 | 44 | 35 | 9 | 75 | 37 | 31 | 7.5 |
| 50 | | 108 | 54 | 43 | 11 | 94 | 47 | 38 | 9.4 |
| 60 | | 129 | 65 | 52 | 13 | 111 | 56 | 44 | 11.3 |
| 75 | | 156 | 78 | 62 | 16 | 140 | 70 | 57 | 14 |
| 100 | | 212 | 106 | 85 | 22 | 182 | 93 | 74 | 18 |
| 125 | | 268 | 134 | 108 | 27 | 228 | 114 | 93 | 23 |
| 150 | | 311 | 155 | 124 | 31 | | 137 | 110 | 28 |
| 200 | | 415 | 208 | 166 | 43 | | 182 | 145 | 37 |

### III. Three-Phase AC Motors.

| | Induction Type<br>Squirrel-Cage and Wound Rotor | | | | | Synchronous Type<br>Unity Power Factor | | | |
|---|---|---|---|---|---|---|---|---|---|
| HP | 110V. | 220V.* | 440V. | 550V. | 2200 V. | 220 V.* | 440V. | 550V. | 2200 V. |
| ½ | 5 | 2.5 | 1.3 | 1 | .. | | ... | ... | ... |
| ¾ | 5.4 | 2.8 | 1.4 | 1.1 | .. | ... | ... | ... | ... |
| 1 | 6.6 | 3.3 | 1.7 | 1.3 | .. | ... | ... | ... | ... |
| 1½ | 9.4 | 4.7 | 2.4 | 2.0 | .. | ... | ... | ... | ... |
| 2 | 12 | 6 | 3 | 2.4 | .. | ... | ... | ... | ... |
| 3 | ... | 9 | 4.5 | 4 | .. | ... | ... | ... | ... |
| 5 | ... | 15 | 7.5 | 6 | .. | ... | ... | ... | ... |
| 7½ | ... | 22 | 11 | 9 | .. | ... | ... | ... | ... |
| 10 | ... | 27 | 14 | 11 | .. | ... | ... | ... | ... |
| 15 | ... | 38 | 19 | 15 | .. | ... | ... | ... | ... |
| 20 | ... | 52 | 26 | 21 | .. | .. | .. | ... | ... |
| 25 | ... | 64 | 32 | 26 | 7 | 54 | 27 | 22 | 5.4 |
| 30 | ... | 77 | 39 | 31 | 8 | 65 | 33 | 26 | 6.5 |
| 40 | ... | 101 | 51 | 40 | 10 | 86 | 43 | 35 | 8.6 |
| 50 | ... | 125 | 63 | 50 | 13 | 108 | 54 | 44 | 10.8 |
| 60 | ... | 149 | 75 | 60 | 15 | 128 | 64 | 51 | 13 |
| 75 | ... | 180 | 90 | 72 | 19 | 161 | 81 | 65 | 16 |
| 100 | ... | 246 | 123 | 98 | 25 | 211 | 106 | 85 | 21 |
| 125 | ... | 310 | 155 | 124 | 32 | 264 | 132 | 106 | 26 |
| 150 | ... | 360 | 180 | 144 | 36 | ... | 158 | 127 | 32 |
| 200 | ... | 480 | 240 | 195 | 49 | .. | 210 | 168 | 42 |

* For full-load currents of 208 and 200-volt motors, increase the corresponding 220-volt motor full-load current by 6 and 10 percent, respectively.

## IV. DC Motors. Amperes at Full Load.

| HP | 115V. | 230V. | 550V. | HP | 115V. | 230V. | 550V. |
|---|---|---|---|---|---|---|---|
| ½ | 4.5 | 2.3 | | 25 | 185 | 92 | 38 |
| ¾ | 6.5 | 3.3 | 1 4 | 30 | 220 | 110 | 45 |
| 1 | 8.4 | 4.2 | 1.7 | 40 | 294 | 146 | 61 |
| 1½ | 12.5 | 6.3 | 2.6 | 50 | 364 | 180 | 75 |
| 2 | 16.1 | 8.3 | 3.4 | 60 | 436 | 215 | 90 |
| 3 | 23.0 | 12.3 | 5.0 | 75 | 540 | 268 | 111 |
| 5 | 40 | 19.8 | 6.2 | 100 | . . | 357 | 146 |
| 7½ | 58 | 28.7 | 12.0 | 125 | . | 443 | 184 |
| 10 | 75 | 38 | 16 | 150 | | | 202 |
| 15 | 112 | 56 | 23 | 200 | | | 295 |
| 20 | 140 | 74 | 30 | | | | |

## CONDUIT SIZES

### (Cables Above 600 Volts, Also Control Cables. Cables of Equal Diameter.)

| Number of Cables in Conduit | NOMINAL SIZE OF CONDUIT* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ½″ | ¾″ | 1″ | 1¼″ | 1½″ | 2″ | 2½″ | 3″ | 3½″ | 4″ | 4½″ | 5″ |
| | MAXIMUM CABLE DIAMETER IN INCHES | | | | | | | | | | | |
| 1 | .46 | 61 | 78 | 1.03 | 1.20 | 1 54 | 1.84 | 2 29 | 2 67 | 3.01 | 3 37 | 3.77 |
| 2 | .25 | .33 | 42 | .55 | .64 | .82 | .98 | 1.22 | 1.42 | 1.61 | 1.80 | 2.02 |
| 3 | .23 | 31 | 39 | 52 | .60 | 77 | 92 | 1 15 | 1.33 | 1.50 | 1.68 | 1.89 |
| 4 | 20 | 26 | 33 | .44 | .51 | 65 | .78 | .97 | 1.13 | 1.27 | 1.42 | 1.59 |
| 5 | | .22 | .28 | .37 | .43 | .55 | .66 | .82 | .95 | 1.08 | 1.21 | 1.35 |
| 6 | | .20 | .26 | .34 | .40 | .51 | .61 | .76 | .89 | 1 00 | 1.12 | 1.25 |
| 7 | | .19 | .24 | .32 | .37 | .47 | .57 | .70 | .82 | .93 | 1.04 | 1.16 |
| 8 | | | 22 | .30 | .35 | .44 | .53 | .66 | .76 | .86 | .97 | 1.08 |
| 9 | | | .21 | .28 | .33 | .42 | 50 | .62 | .72 | .81 | .91 | 1.02 |

EXAMPLE: A 1½″ conduit will accommodate 3 cables with diam. .52″ to .60″.

* Conduit sizes are based on a straight run of 200′, 100′ with 2-90° bends or 50′ with 3-90° bends. For installations exceeding these limiting conditions use one or two conduit sizes larger.

## DIMENSIONS OF CONDUIT OR TUBING

| Size (Inches) | Internal Diameter (Inches) | Area (Sq. Inches) | Size (Inches) | Internal Diameter (Inches) | Area (Sq Inches) |
|---|---|---|---|---|---|
| ½ | .622 | .30 | 3 | 3.068 | 7.38 |
| ¾ | .824 | .53 | 3½ | 3.548 | 9.90 |
| 1 | 1.049 | .86 | 4 | 4.026 | 12.72 |
| 1¼ | 1.380 | 1.50 | 4½ | 4.506 | 15.95 |
| 1½ | 1.610 | 2.04 | 5 | 5.047 | 20.00 |
| 2 | 2.067 | 3.36 | 6 | 6.065 | 28.89 |
| 2½ | 2.469 | 4.79 | | | |

## APPROXIMATE AMPERES FOR INDUCTION MOTORS

| HP of Motor | 220 Volts | | HP of Motor | 220 Volts | |
|---|---|---|---|---|---|
| | 2-Ph. | 3-Ph. | | 2-Ph. | 3-Ph. |
| .5 | 1.7 | 2.0 | 50. | 108. | 125. |
| 1.0 | 3.0 | 3.5 | 60. | 130. | 150. |
| 2.0 | 5.5 | 6.4 | 75. | 160. | 185. |
| 3.0 | 8.0 | 9.2 | 100. | 215. | 250. |
| 5.0 | 13. | 15. | 125. | 260. | 300. |
| 7.5 | 19. | 22. | 150. | 320. | 370. |
| 10. | 24. | 28. | 175. | 360. | 420. |
| 15. | 35. | 40. | 200. | 415. | 480. |
| 20. | 45. | 52. | 225. | 460. | 530. |
| 25. | 56. | 65. | 250. | 520. | 600. |
| 30. | 66 | 75. | 275 | 570 | 660. |
| 40. | 87. | 100. | 300. | 620. | 720. |

For 110 volts, use 2; for 440, use 1/2; for 550, use 2/5; for 1100, use 1/5; and for 2200, use 1/10 of the above values. For single phase motors use twice the value for two phase motors.

WEAR TABLE (See Fig. 96)

| *Date* | *A* | *B* | *C* | *D* |
|---|---|---|---|---|
| 4–1–40 | .030 | .032 | .031 | .029 |
| 4–6–41 | .031 | .032 | .030 | .029 |
| 4–7–42 | .032 | .033 | .029 | .028 |
| 4–2–43 | .033 | .033 | .028 | .028 |

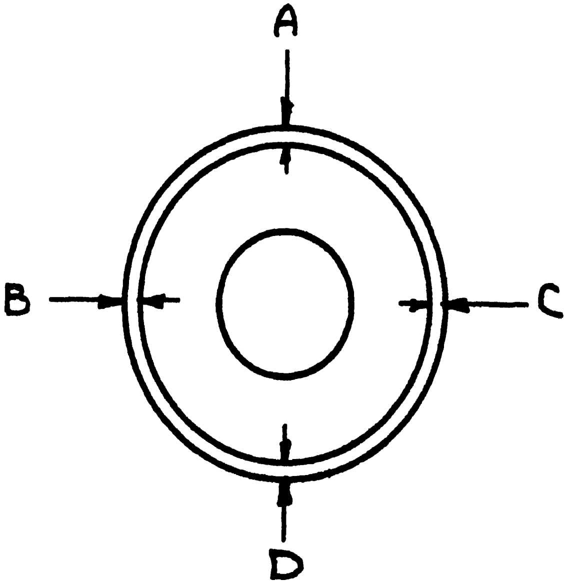
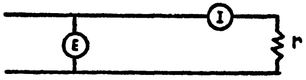


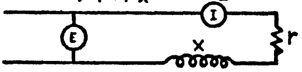
FIG. 96. Gap clearance diagram, showing commutator end for DC motors and drive shaft end for AC motors. See accompanying table, which shows wear at dates indicated.

## FORMULA FOR DETERMINING AC IN AC CIRCUITS

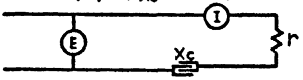
$$I=\frac{E}{r}$$



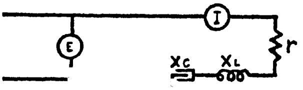
$$I=\frac{E}{\sqrt{r^2+X^2}}=\frac{E}{Z}$$



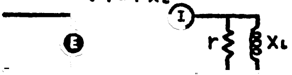
$$I=\frac{E}{\sqrt{r^2+X_C^2}}=\frac{E}{Z}$$



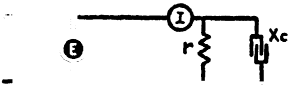
$$I=\frac{E}{\sqrt{r^2+(X_L-X_C)^2}}=\frac{E}{Z}$$



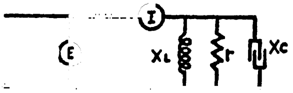
$$I=\frac{E}{\frac{rX_L}{\sqrt{r^2+X_L^2}}}=\frac{E}{Z}$$



$$I=\frac{E}{\frac{rX_C}{\sqrt{r^2+X_C^2}}}=\frac{E}{Z}$$



$$I=\frac{E}{\frac{rX_LX_C}{\sqrt{X_L^2X_C^2+r^2(X_L-X_C)^2}}}=\frac{E}{Z}$$



**Meaning of abbreviations in the above and following sets of formulas:**

r = Resistance in Ohms

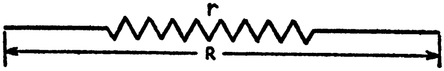
$X_L$ = Inductive reactance in Ohms = $2\pi fL$
$X_C$ = Condensive Reactance in Ohms = $1 \div 2\pi fc$

f = frequency
L = ind. in Henrys
c = capacity in Farads

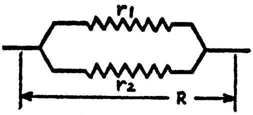
Z = Impedance in Ohms
I = Current in Amperes
E = Pressure in Volts

## FORMULAS FOR COMBINING RESISTANCE AND REACTANCE

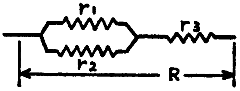
$$R = r$$



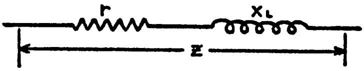
$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2}} = \frac{r_1 r_2}{r_1 + r_2}$$



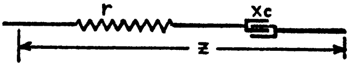
$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2}} + r_3 = \frac{r_1 r_2}{r_1 + r_2} + r_3$$



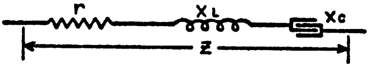
$$Z = \sqrt{r^2 + X_L^2}$$



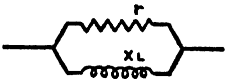
$$Z = \sqrt{r^2 + X_c^2}$$



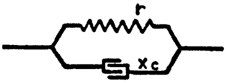
$$Z = \sqrt{r^2 + (X_L - X_c)^2}$$



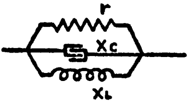
$$Z = \frac{1}{\sqrt{\left(\frac{1}{r}\right)^2 + \left(\frac{1}{X_L}\right)^2}} = \frac{r X_L}{\sqrt{r^2 + X_L^2}}$$



$$Z = \frac{1}{\sqrt{\left(\frac{1}{r}\right)^2 + \left(\frac{1}{X_c}\right)^2}} = \frac{r X_c}{\sqrt{r^2 + X_c^2}}$$



$$Z = \frac{1}{\sqrt{\left(\frac{1}{r}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_c}\right)^2}} = \frac{r X_L X_c}{\sqrt{X_L^2 X_c^2 + r^2 (X_L - X_c)^2}}$$



| To Find | Direct Current | ALTERNATING CURRENT | | |
|---|---|---|---|---|
| | | Single Phase | 2 Phase*—Four Wire | Three Phase |
| Amperes when Horsepower is known | $\frac{HP \times 746}{E \times \% \text{ Eff.}}$ | $\frac{HP \times 746}{E \times \% \text{ Eff.} \times P.F.}$ | $\frac{HP \times 746}{2 \times E \times \% \text{ Eff.} \times P.F.}$ | $\frac{HP \times 746}{1.73 \times E \times \% \text{ Eff.} \times P.F.}$ |
| Amperes when Kilowatts is known | $\frac{kw. \times 1000}{E}$ | $\frac{kw \times 1000}{E \times P.F.}$ | $\frac{kw. \times 1000}{2 \times E \times P.F.}$ | $\frac{kw. \times 1000}{1.73 \times E \times P.F.}$ |
| Amperes when Kv-a. is known | | $\frac{Kv\text{-}a. \times 1000}{E}$ | $\frac{Kv\text{-}a \times 1000}{2 \times E}$ | $\frac{Kv\text{-}a \times 1000}{1.73 \times E}$ |
| Kilowatts | $\frac{I \times E}{1000}$ | $\frac{I \times E \times P.F.}{1000}$ | $\frac{I \times E \times 2 \times P.F.}{1000}$ | $\frac{I \times E \times 1.73 \times P.F.}{1000}$ |
| Kv-a. | | $\frac{I \times E}{1000}$ | $\frac{I \times E \times 2}{1000}$ | $\frac{I \times E \times 1.73}{1000}$ |
| Horsepower—(output) | $\frac{I \times E \times \% \text{ Eff.}}{746}$ | $\frac{I \times E \times \% \text{ Eff.} \times P.F.}{746}$ | $\frac{I \times E \times 2 \times \% \text{ Eff.} \times P.F.}{746}$ | $\frac{I \times E \times 1.73 \times \% \text{ Eff} \times P.F.}{746}$ |

I = Amperes; E = Volts; % Eff. = Precent Efficiency; P.F. = Power Factor; kw = Kilowatts; Kv-a. = Kilovolt-amperes; HP = Horsepower.

* For three-wire, two-phase circuits the current in the common conductor is 1.41 times that in either of the other two conductors.

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